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The TREND IN ENGINEERING

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In this issue:

- The University's Part in Stream-Pollution Control
- Effects of Low Temperatures on Electric Strain Gages
- Phosphate Fertilizer by the Fusion of Phosphate Rock and Olivine
- Dynamic Design of Bituminous Pavements
- Road Builders to Meet
- Ordinates for Axially Symmetric Supersonic Nozzles
- Electrothermic Production of Sodium

January, 1950

VOL. 2, No. 1

TO SOME PEOPLE modern technology is plainly evil. To them, the more gadgets the more unpalatable is life. . . . There are others of our contemporaries who have an almost opposite view of the machine. You will find them all over the world. What they say is exuberant and uncritical. 'Of course technology is good,' they say, 'for it produces more and more things; and isn't production the answer to everything?'. . .

"I believe in the great potentialities for well-being of the machine and technology; and though they do hold a real threat of enslavement and frustration for the human spirit, I believe these dangers can be averted. I believe that through the methods of democracy the world of technology holds out the greatest opportunity in all history for the development of the individual, according to his own talents, aspirations, and willingness to shoulder the responsibilities of a free man. I believe men can make themselves free. Men can direct technology so that it can carry mankind toward the fulfillment of the greatest promise for human life and the human spirit in all history.

"But this result is by no means inevitable. It is equally possible that technology may reap a harvest of bitter fruit.

"More huge cyclotrons and nuclear research reactors are not enough. More fine laboratories, more extensive projects in physical and social research are not enough. More *use* of technology, more factories, more gadgets, whether in this country or in the undeveloped reaches of Africa and Asia and South America is not enough. . . .

"Unless the applications of research and technology are consciously related to a central purpose of human welfare, unless technology is defined and directed by those who believe in people and in democratic and ethical ends and means, it could be that the more research money we spend the further we miss the mark. It is like driving an automobile that is going in the wrong direction; the faster and faster you drive, the farther away from your destination you will be."

—D. E. LILIENTHAL, "Machines with and Without Freedom," *S.R.L.*, August 6, 1949.

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to co-ordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;
(2) to undertake extended research and to publish reports on engineering and scientific problems;
(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

For administrative purposes the work of the Station is organized into nine divisions:

1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgy, Ceramics
9. Physics Standards and Tests

The control of the Station is vested in a Station Board consisting of the President of the University, the Dean of the College of Engineering as chairman, the Director of the Station, and members of the faculty, representative of the administrative divisions. The Board determines the character of the investigations to be undertaken and supervises the work.

The Station offers a substantial number of research fellowships to highly qualified graduate students who work under the direct supervision of the faculty of the various divisions. The results of the investigations are published in the form of bulletins, technical notes, and reports. Reprints of articles by members of the engineering faculty and graduate students published in recognized technical journals are also issued by the Station. Requests for copies of the publications and inquiries for information on engineering and industrial problems should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

January, 1950

The TREND IN ENGINEERING

at the University of Washington

Vol. 2 No. 1

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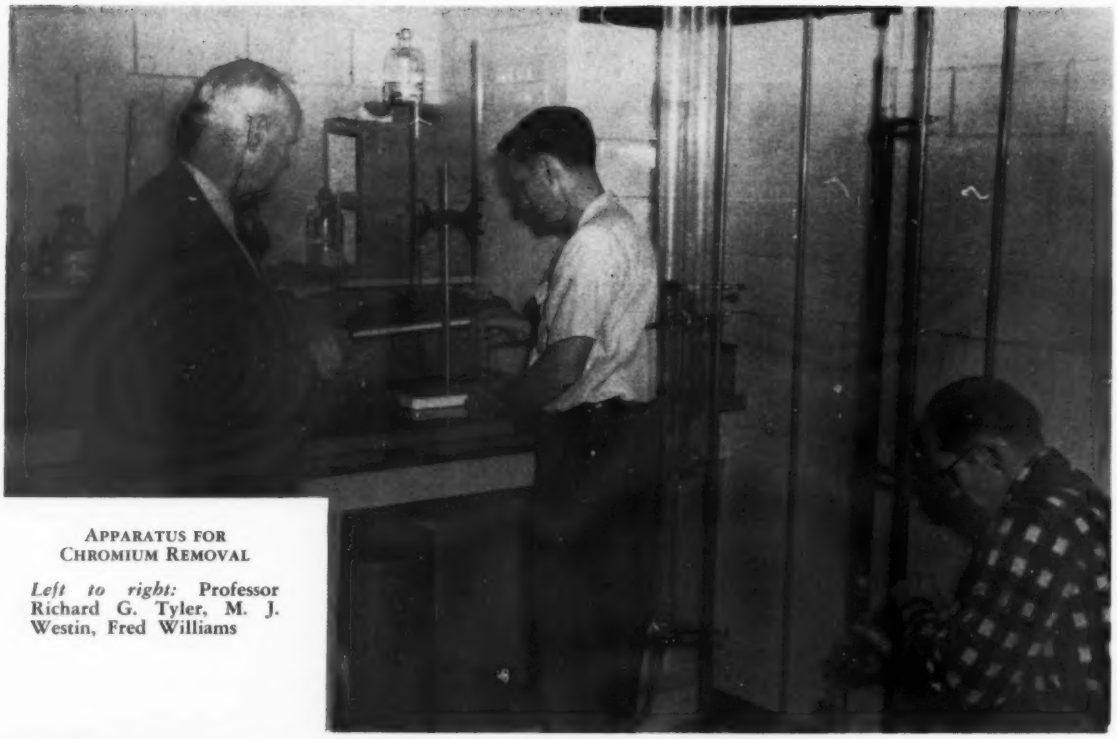
COVER

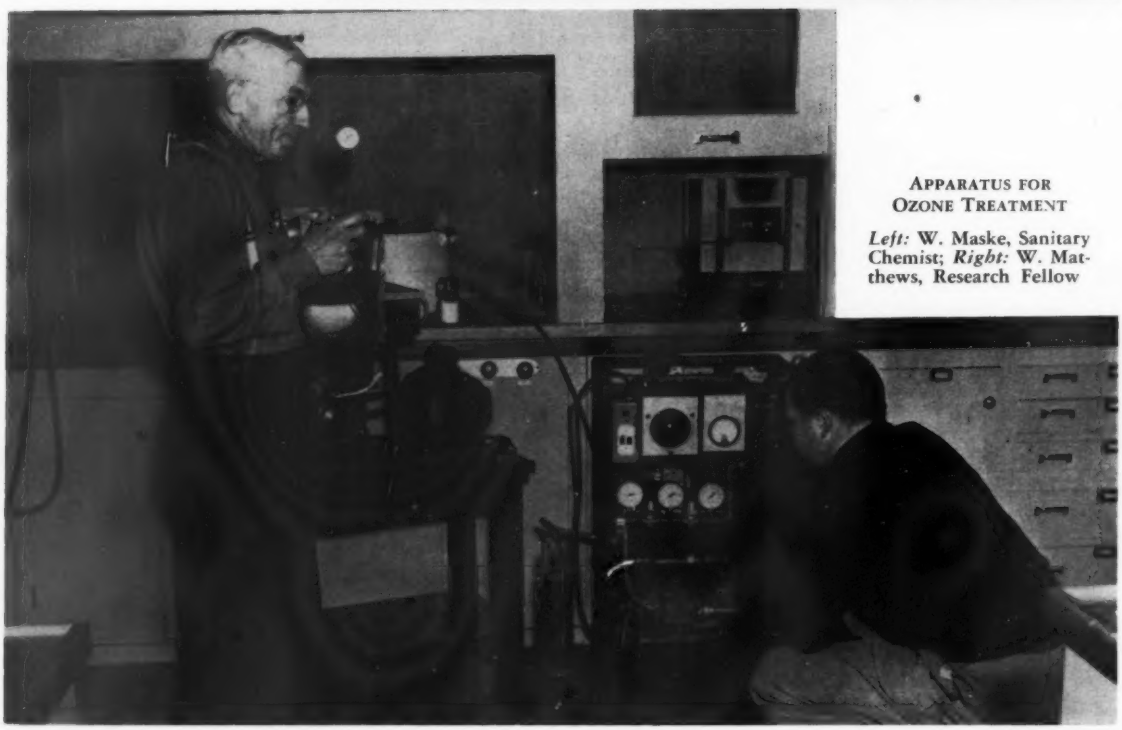
Fish killed by pollution along the 5-mile strip of beach between Mukilteo and Everett, July 31, 1949. The fish were chiefly herring, with a few salmon. Photograph courtesy of Frank Ermance, Everett, Washington.

Inset: Salmon jumping Brooks Falls, Alaska. Photograph courtesy of U. S. Fish and Wildlife Service.



APPARATUS FOR CHROMIUM REMOVAL

Left to right: Professor Richard G. Tyler, M. J. Westin, Fred Williams

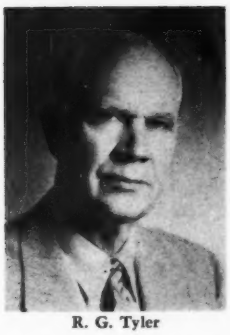


APPARATUS FOR OZONE TREATMENT

Left: W. Maske, Sanitary Chemist; *Right:* W. Matthews, Research Fellow

The University's Part in Stream-Pollution Control

RICHARD G. TYLER
Professor of Sanitary Engineering


R. G. Tyler

One of the functions of a state educational institution is to provide technical assistance from its specialists to aid governmental agencies or private interests in solving their technical problems which are of public importance. A case in point is the current discussion in the local press concerning the conservation of the state's fishery resources. One of the causes of the drastic curtailment of this resource has been attributed to unsound and illegal fishing practices. Criticism has been directed also against the construction of dams across the Columbia and other rivers, which produced the power so effective in winning the war and in increasing payrolls throughout the state. In fact, the continued growth and prosperity of the state may be said to depend on this large production of low cost power to a greater extent than on any other single factor. But part of the blame also has been placed on the pollution of Puget Sound waters by industry, specifically the pulp and paper industry. The writer is not in a position to judge as to the relative responsibilities of these three factors with reference to the alleged decrease in salmon runs but he does recognize the importance of saving all three of these resources if the state is to continue to grow and provide adequate employment for its increasing population.

With regard to the effects of stream pollution by the pulp industry on the survival or expansion of fishing as a vital state industry, the writer has made extended studies over a considerable period of time in which he has sought to find a method for treating the pulp-mill wastes so that both the fisheries and the pulp industry may continue not only to survive, but to expand. The sanitary engineer or chemist is helping both of these resources by the work he does in solving the pulp mill's waste problems.

In the first place, the water resources of the Pacific Northwest, unequaled in this nation both as to abundance of supply and as to purity and potability, are our greatest asset, and their conservation and protection from pollution beyond what is permissible under our national and state sanitary codes is essential. It should, however, be kept in mind that since the beginning of time rivers have been utilized necessarily to transport waste products from the community for the sake of the community's health and welfare. It has been generally accepted by the courts of this country that a stream cannot pass from its source to the sea and keep its original purity uncontaminated by the wastes from the population along its banks. It has, however, also been well established by the courts that sewage and industrial wastes being discharged into the streams must first receive adequate treatment so that the health of the community is not jeopardized nor the use of the stream for fishing or recreational purposes impaired.

It is therefore necessary in the public interest that municipalities, industries, shipowners, and others who may be discharging pollutional materials into the waters of this state, should adequately treat their wastes before discharging them into these waters. But it is also important that people should recognize the difficulties involved in treating wastes such as those of the pulp and paper industry. A number of methods have been developed recently for treating these wastes but all are very costly and some have been tried out only on a pilot-plant scale. However, several of the state's pulp mills have already developed solutions to their particular problems, though the methods used are not necessarily adaptable to the other mills still requiring waste-treatment plants.

Sanitary engineers have been able to develop methods for treating sewage and most industrial wastes adequately for conserving the beauty and usefulness of our rivers, but a major handicap lies in the fact that the waste from certain industries, such as the pulp and paper industry, are so strong in their oxygen requirements that adequate treatment can only be carried out at an extremely high cost to the industry. The charges against such industries for producing adequate treatment of their wastes may be too great for them to survive at existing markets for their products. The cost necessarily will be reflected in increased prices to the consumer of pulp and paper and will thus be paid ultimately by the public. It is obviously of interest to the public that ways be found for utilizing the waste by-products so as to bring in a return which

will help carry the cost of the required treatment. It is at this point that progress has been too slow to keep ahead of the need for disposal methods which would be, at least partly, self-supporting.

The writer has been engaged for the past ten or twelve years in investigating methods for treating sulfite waste liquor and has had an opportunity to become acquainted with the various methods that have been developed both here and elsewhere for disposal or utilization of its constituents in the production of marketable by-products. For years the pulp industry has been aware of its disposal problem and of its responsibility with reference to maintaining a reasonable water purity. It has spent large sums of money in carrying out research in an attempt to solve this crucial problem. As an example of its efforts along this line, the local mills have spent over $300,000 on a six-year research program carried out by the University's technical experts to find methods for disposing of their waste liquor or of utilizing said liquor in producing commercially useful products. The mills of Wisconsin have had a similarly extensive research project in progress for about ten years, and during the past three or four years the National Stream Improvement Council, financed by the pulp plants all over the United States, has been spending large sums on additional investigations and studies. Thus a great deal of effort has been put into finding a solution of the pulp-waste problem with considerable success. The methods developed, however, still need to be tested on a semiplant scale before the expenditure of the millions of dollars required for a full-plant scale could be confidently undertaken.

In the production of pulp, a little over half the log remains in solution in the waste liquor produced. From each ton of wood chips, therefore, about 1,050 pounds of waste substances and 950 pounds of cellulose pulp are produced. In the waste, there are some 750 pounds of lignin, which is the cementing substance in the wood, accompanied by 250 pounds of wood sugars, and about 50 pounds of resins and miscellaneous extractives. The reason why it is so extremely difficult and costly to recover useful products from this waste is because of their great dilution as discharged from the mill. Difficulties in concentrating the waste also are great because of its corrosive properties and the scale which is produced by the large amount of calcium present in the cooking acid. The 250 pounds of sugar which is the principal consumer of oxygen from dilution waters is actually diluted to only 2½ or 3 per cent concentration. In fact, all of the solids in the liquor total only about 12 per cent of the weight of liquor produced. Obviously it is not feasible to concentrate the very soluble sugars to a point where they could be recovered as such. It is possible, however, to utilize them as food for yeast or bacteria since sugars form a natural food for microorganisms which they prefer to any other food.

The elimination of sugars, therefore, is the major problem from the standpoint of the effect of pulp-waste liquor on fish. If its demand for oxygen reduces the oxygen dissolved in the water of a stream to as low as two or three parts per million (pounds per million pounds of water), fish cannot survive in it. The State Pollution Control Commission, therefore, requires that all surface waters of the state must have at least five parts per million of dissolved oxygen remaining after supplying all pollutional demands, in order that an adequate supply will be present at all times to insure the survival and propagation of fish.

The oxygen in the state's streams must be shared on a fair basis by the fish, sewage from municipalities, and wastes from industrial plants. Both the cities and industries therefore are being required to install adequate treatment plants in order to maintain the required amount of dissolved oxygen for supporting fish life. The pulp-mill problem is difficult because its oxygen demand is considerably greater than the similar demand by domestic sewage. In fact, the oxygen requirement for sulfite waste liquor for each ton of pulp produced is approximately equal to that of the sewage from a town of three thousand persons. In other words, the population equivalent, as this ratio is designated among sanitary engineers, is thus approximately three thousand. This, of course, varies among the different mills, because of the differences in their processes and production. The cost of treating a waste is a function of its oxygen demand or population equivalent, so it is obvious that a two-hundred-ton pulp plant would have a problem in treating its waste comparable to that of the city of Seattle in constructing a disposal plant to treat all of its sewage.

It is, therefore, readily apparent why most of the research that has been done on sulfite waste liquor has been directed toward the recovery of the various constituents of the waste so as to utilize them in securing a financial return that will at least bear part of the excessively high cost of treatment required. Here at the University, for example, we have worked out several methods for utilizing the waste. To date, none of these have been carried further than the small pilot-plant stage.

Perhaps the most promising of these experiments had to do with the growing of yeast on the waste liquor for supplying the protein content for stock feed. The fodder yeast, *Torula utilis*, was grown on the sugars in the waste in the apparatus shown

in Fig. 1. Waste liquor is placed in the vertical plastic tube and seeded with yeast. Large quantities of air are blown through the mixture, producing foam which overflows into the parallel tube attached to the right of the main propagator. This foam provides excellent contact between the yeast, liquor, and air, which is essential to the process. It flows downward and re-enters the main propagator as indicated in the figure, recirculating as long as required for efficient yeast growth. The waste liquor is fed continuously to the propagator and is discharged near the top of the tube when its sugars have been utilized. Thence it flows to a centrifuge for separation of the yeast which is dried on heated drums or with spray dryers, and is marketed in flaky or powdered form.

A similar method was used in Germany during the war for producing yeast for both animal and human consumption. Recently a large scale pilot plant was constructed at Rhinelander, Wisconsin, and has been in operation now for some months. It is producing yeast commercially, its total output being used for getting cost estimates on a full-scale plant. The University research is now in abeyance awaiting the outcome of the Rhinelander pilot-plant studies.

The yeast, which is being utilized primarily for feeding chickens, contains both protein and also a large quantity of the various vitamins. The Chemical Engineering Department of the University of Washington has operated a large enough pilot plant in cooperation with our Sanitary Laboratory to produce yeast which was used in feeding tests on rats and chickens, thus proving to our satisfaction its suitability for use in stock foods.

Fig. 2 shows the results obtainable when treating sulfite waste liquor on high-rate trickling filters such as are used at sewage-disposal plants. From this figure it is apparent that up to 75 per cent of the BOD can be removed from the liquor by this process, but the installation would be very costly and no financial return would be obtainable. It was only after carrying out extensive tests on a battery of ten such filters operating under all probable conditions that it was decided that the producing of yeast from the liquor gave a more practical solution of the problem while producing approximately the same purification of the waste at a smaller cost.

Considerable progress has already been made by some of the mills of this state in finding solutions to the sulfite waste problem. At Hoquiam, Washington, Rayonier Incorporated is storing its waste liquor in a large pond where it is held during the period of low flow in the Chehalis River which supplies Grays Harbor with much of the latter's oxygen supply. The critical period occurs in the

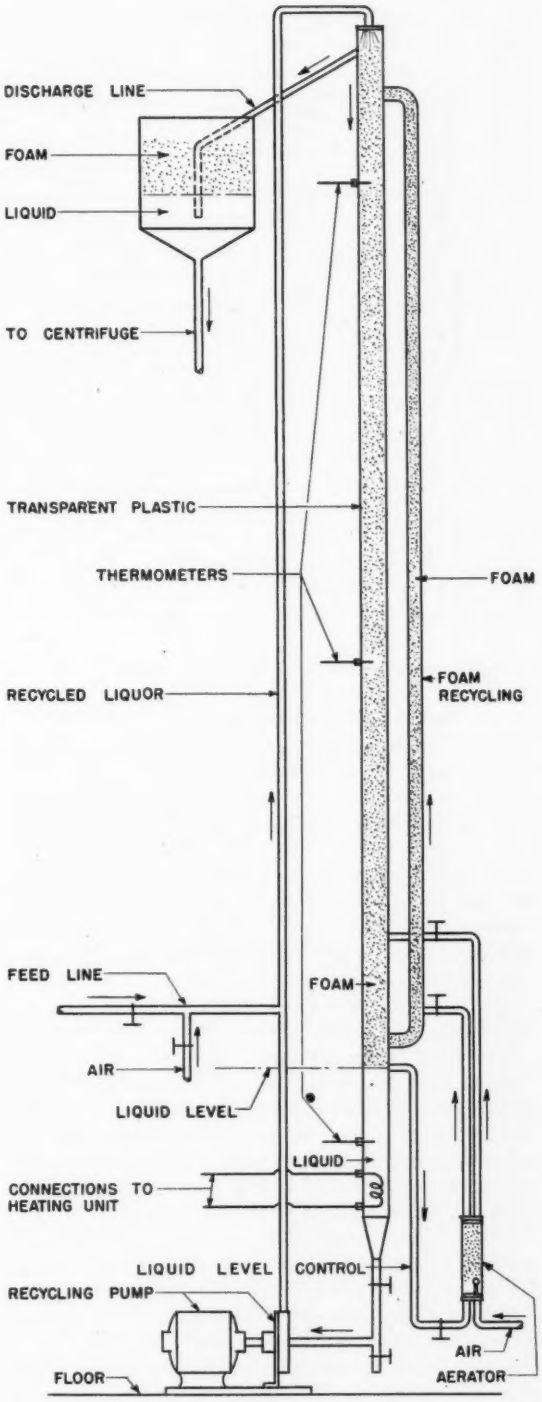


FIG. 1. YEAST PROPAGATOR

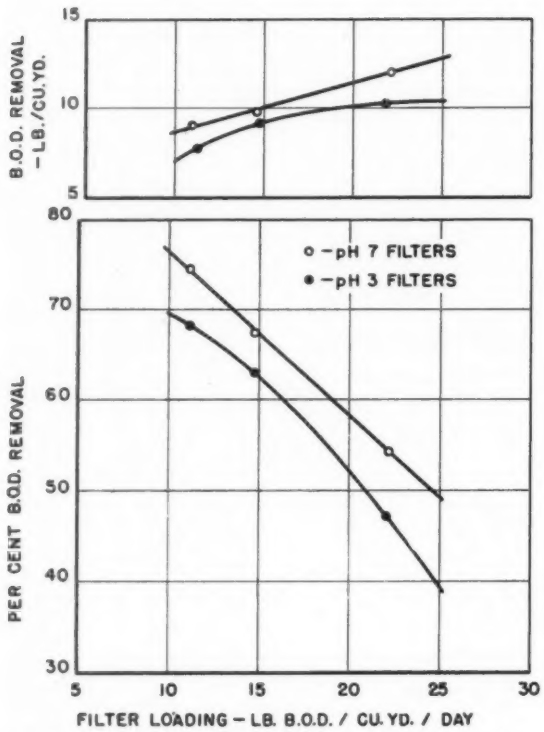


FIG. 2. RELATIONSHIP OF FILTER LOADING TO BOD REMOVAL

summer when the low river flow brings an inadequate oxygen supply for oxidizing this waste from the mill, with the help of additional oxygen from the sea water interchanged per tide. The stored liquor is discharged into the harbor after the fall and winter rains have increased the river flow beyond a minimum value required to keep an adequate oxygen content in the harbor for meeting the state's requirements.

The same pulp company also has changed the process of manufacture at its Shelton plant from the calcium bisulfite process, which is responsible for so much of the present pollution problem, to an ammonium bisulfite process in which the waste liquor can be evaporated and burned so that none of it is discharged into Oakland Bay.

The Puget Sound Pulp and Timber Company in Bellingham during the war constructed a plant for making ethyl alcohol from all of its waste liquor. This plant has now been in operation for several years, but a recent drop in the price of alcohol has been quite discouraging to those who had hoped that this would be a solution to the waste-liquor problem. It should be added that, while fermentation of the sugars does not remove all of the oxygen demand of the liquor, the Bellingham plant is also processing the wastes from the alcohol plant, which thus completely solves the waste problem for the Bellingham mill.

A question which naturally arises at this point is why don't the other local pulp mills also use some of these methods for solving their problems? One answer is that other plants do not have the location that makes the Hoquiam solution feasible. Or, mills making a lower priced pulp cannot spend as much for waste disposal as can a mill producing a higher priced commodity. Another big problem in treating sulfite waste liquor is in finding adequate markets for its by-products. For example, the Bellingham plant produces more alcohol than can be used on the Pacific coast so that it has to be shipped east at a considerable expense for freight. The development of local industries which can utilize alcohol as their raw material would thus assist materially in solving the waste-liquor problem by stabilizing the market for alcohol. Obviously only one mill on the west coast can use this method because of market limitations. Similarly, the production of yeast as heretofore mentioned, to be a successful solution of this problem, will require markets for consuming a very large quantity of protein. It would undoubtedly require a much larger territory than the state of Washington to utilize the yeast that could be produced from the state's pulp mills. The building up of such markets is a problem which requires time and is one of the factors that is preventing a more rapid solution of the pulp-waste problem.

A number of other products have been produced from this liquor, but those herein described probably have the greatest possibility for bringing in a sufficient financial return to bear the cost of the required treatment. Activated carbon, lampblack, and ion exchange materials have been produced in the University's laboratories, but economic large scale production of such commodities is still in the future.

Another solution is now being perfected at the recently built Weyerhauser plant at Longview where the magnesium bisulfite process is being developed. It is hoped that this will be the answer for any new plant to be built in this area, but the installation of this process in existing plants may be too expensive in cost of reconstructing such plants for local mills to be able to use it. In this process the waste liquor is evaporated and burned, thus recovering heat and chemicals for re-use in the pulping process. In any of the processes where the waste can be evaporated and then burned, enough heat can probably be produced for operating the entire plant. Such evaporation cannot be done with the

calcium-base liquor at our existing plants, however.

Since the nontoxic disposal problems are produced by the using up of the dissolved oxygen in the water into which the waste or sewage is discharged, the writer proposed some years ago a method of solving this problem of oxygen deficiency by aerating the streams at a point downstream from the waste or sewer outlet where the oxygen had been reduced to the minimum permissible under the state regulations. Oxygen is then readily absorbed as air is bubbled up through the polluted water and the oxidation of the waste accomplished. If the pollution is very heavy it may require another aeration device still farther downstream where the oxygen has again dropped to minimum allowed values. Recently developed methods of producing oxygen from the liquefaction of air followed by its rectification, reduce its cost of production to a point where its use becomes feasible for this aeration process. Since three or four times as much gaseous oxygen can be absorbed as when air is used, a single application will be sufficient in most cases for rehabilitating the stream or harbor. Aerators similar to those used in activated sludge sewage-disposal plants can be used for aerating the stream.

This method has been used at Park Falls, Wisconsin, where the Flambeau River had its oxygen supply so depleted by waste from a pulp mill that fish had disappeared from the river for many miles below the plant. Since several downstream resorts depended upon sport fishing for their survival, they objected strenuously to the disappearance of game fish from the river. The writer inspected the mill and the aerators in the river downstream after the aeration had been in operation for a year, and was informed that fish had returned to the river and had been caught as far upstream as the aerators themselves.

This method cannot be used universally because of the limitations of the equipment to operating depths not greater than fifteen feet. Recently developed aerator nozzles of the American Well Co. type may make air application at greater depths possible. Further problems arise in navigable streams because of objections to placing equipment in them. State authorities also have preferred to have wastes kept out of streams rather than having their detrimental characteristic neutralized by oxidation after being discharged into said streams. There are situations, however, where this method is justified and where its cheaper cost makes it the best solution of the problem.

Part of the responsibility for fish kills falls upon other industries discharging toxic wastes into tide water. Occasional, and sometimes accidental, discharges of metal-plating wastes in our harbors have killed fish. A few other wastes have also been found harmful to fish. All of these must be adequately treated and the University is now seeking effective and economical methods for their treatment through the joint efforts of the Engineering Experiment Station and the Sanitary Engineering Laboratory.

Red tides, as the occasional appearance of certain toxic sea water algae are called, have caused the death of large numbers of fish and shellfish. Because of the reddish color produced by the enormous numbers of these organisms present at such times, oyster growers and fishermen have frequently blamed these kills upon pulp-mill waste which also gives a reddish color to the water when sufficiently concentrated. The cause of these kills, which will continue until methods adequate for combating them can be developed, should be distinguished from those produced by sulfite waste liquor. The red tide problem, however, seriously endangers the fishing industry along the entire western coast of this country and methods for its solution must be developed.

Several research projects are now in progress in our laboratories which have as their objective the more effective treatment of industrial wastes entering the state's surface waters. (See front illustration.) One of these projects is an investigation of the different methods for neutralizing or otherwise disposing of chromium and cyanide wastes from the metal-plating industries. These wastes are very toxic and fish kills have occurred where they have been discharged into local streams. Milton J. Westin is working on this problem under a fellowship jointly sponsored by the State Pollution Control Commission and the Engineering Experiment Station.

Under a similar joint fellowship, Fred W. Williams is investigating methods for treating the white water from pulp mills. This waste has received very little attention up to this time as all efforts have been devoted to solving the more important sulfite waste liquor problem.

A third research fellowship, sponsored by the Rushlight Automatic Sprinkler Company of Portland, Oregon, was awarded to Willard Matthews, who is investigating the uses of ozone in the treatment of both industrial wastes and sewage under Engineering Experiment Station Project No. 72.

All three of these projects are making satisfactory progress and will throw more light on some of the state's pollution problems.

"Research, at present, consists of a blend . . . a judicious mixture of theoretical analysis and experimental trial, of relentless reason and of gifted intuition."—K. W. MILLER, "Fun, Facts and Fancies About Research," *Weld. Res. Supp.*, Nov., 1949.

EFFECTS OF LOW TEMPERATURES ON ELECTRIC STRAIN GAGES*

E. E. DAY
Assistant Professor of Mechanical Engineering

E. E. Day

Introduction

The design of a very simple and cheap yet extremely effective low temperature box is presented along with the techniques and methods used for determining the effects of low temperatures on the strain-sensitivity factor or gage factor of ordinary commercial wire strain gages. The characteristic with which this investigation is concerned, namely, the strain-sensitivity factor, sometimes called the gage factor, is defined as the ratio of unit change in resistance to unit change in strain.

$$\text{S.S.F.} = \frac{\text{Unit change in Resistance}}{\text{Unit change in Strain}} = \frac{\text{ohms/ohm}}{\text{inches/inch}}$$

Everyone by now is quite familiar with the vast new field of engineering applications to which the electric strain gages have been subjected. Originally designed for ordinary temperature operation, their limits have been expanded in both directions until now their range extends over many hundreds of degrees. For these extreme applications, however, special gages are usually constructed and a solution is not found in recourse to standard commercially available gages. The purpose of this investigation is to take these standard gages, apply them in a simple standard way and determine their behavior when subjected to some of these extreme conditions. Because of the great number of types of gages now available, this paper cannot cover many of them, but will, rather, present a successful method which can easily be applied to all gages.

APPARATUS AND METHOD

Description of Equipment

Besides the special low temperature box which will be described later in this paper, many standard pieces of laboratory apparatus were incorporated into the complete equipment, with such alterations as would adapt them to the purpose of this particular work. The galvanometer used in conjunction with the Wheatstone bridge was of the spot-light type manufactured by Rubicon in Philadelphia. It was of a relatively high sensitivity, being 0.00785

* Condensed from the paper, "Characteristics of Electric Strain Gages at Low Temperature," by E. E. Day and A. H. Sevand, presented by E. E. Day before the Society for Experimental Stress Analysis, Detroit, Michigan, May 19, 1949.

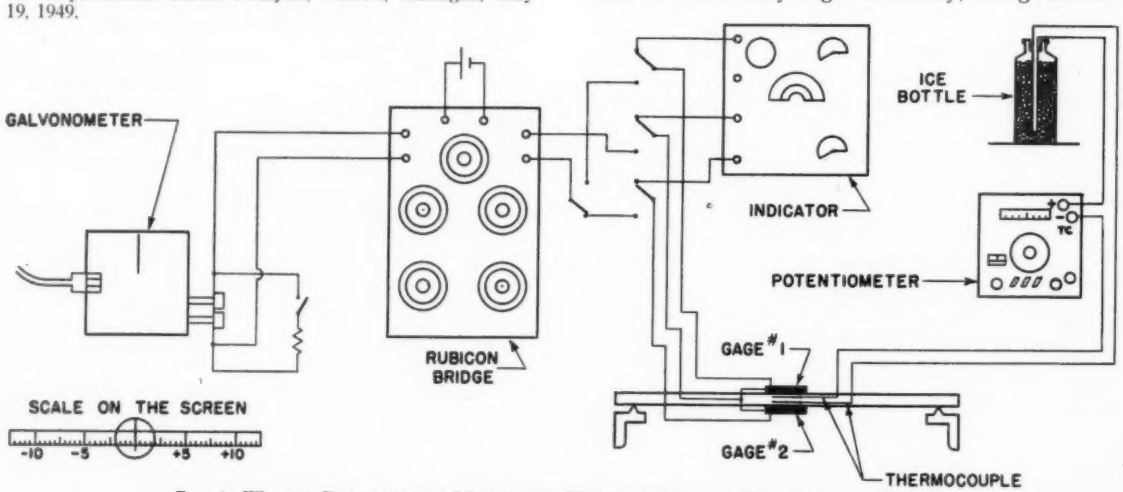


FIG. 1. WIRING DIAGRAM FOR MEASURING TEMPERATURE AND RESISTANCE OF GAGES

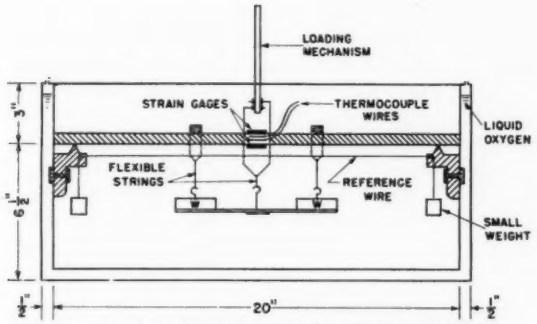


FIG. 2. SIDE VIEW OF LOW TEMPERATURE BOX

mu a per millimeter. To increase further the accuracy of the scale and spread it out more, the scale in the box was removed and the hairline was refocused on a ground-glass screen placed 21 in. away from the previous scale position. A scale with 20 divisions was placed on this screen with the result that 94 of these divisions were found to represent .1-ohm change in resistance on the bridge.

The bridge used (Fig. 1) was a Rubicon multiple bridge. The multiplying factor was set at .1 ohm.

To determine the deflection of a beam due to an external load is quite a difficult accomplishment especially if the beam is enclosed in a box and exposed to a very low temperature. The problems in connection with this are manifold regardless of the system chosen. With mechanical equipment there is the problem of heat conduction from the outside giving rise to such rapid temperature changes as to destroy the possibilities of nearly steady state conditions. In electrical methods, use of a capacitance gage presents the difficulties involved in a capacitance bridge. In the work to be described, an interferometer was adapted to measure the change in distance between the beam and a datum point by means of counting interference bands. This necessitated the use of openings through the chamber walls covered by windows, which could not be kept free of frost. At last a Gaertner two-telescope cathetometer scaled to read to 0.0001 in. was used and was found to repeat quite consistently. The optical elements, however, were slightly rearranged for more power and better to suit the particular conditions of the low temperature box. The lower telescope was removed and the optical tube carrying the objective of the other telescope was extended about twice the original length by means of inserting a bakelite tube of the proper size. This change accomplished several purposes. First, it increased the power of the telescope and decreased the distance from the object to the target. Second, it removed the objective far enough from the cathetometer so that it could be introduced into the chamber of the box through a small oval opening and yet allow the body of the instrument to remain outside for easy access. The low heat conductivity of the plastic tube and ample baffling around the hole through which it was introduced prevented any appreciable effect on the temperature within the chamber.

Fig. 2 shows a cross section which reveals the simple features of the box. The inner chamber itself was made of 16-gage 18-8 stainless steel. It was so welded that the top was open but the remaining sides and bottom were double walled to form a one-half-inch jacket for the liquid oxygen. The only openings in this jacket were four corner holes through which tubes were inserted for introducing the oxygen and for allowing the gas to escape. This double-walled chamber was surrounded by 5 in. of rockwool insulation and placed in a wooden box 30 in. by 20 in. by 20 in. The insulation thickness was calculated so that it would require 24 hours for the temperature within the chamber to travel from —295° F to + 70° F. Repeated experimental results showed this time to be 23.5 hours for a change from —295° F to 20° F. Fig. 3 is a fairly representative curve showing this temperature–time relation.

Fig. 2 clearly shows the method of supporting the beam upon which the gages were cemented as well as the position of the thermocouple for determining the gage temperature. Also in this figure the position of the weights on the pan and the means of raising and lowering this pan with a small fiber rod through an opening in the top of the chamber can be seen.

Fig. 2 shows that the knife edges carrying the 0.187-in. by 0.500-in. beam also carry a 0.001-in. steel wire held taut by small weights suspended at each end after the wire has passed over the supports. This wire, though free to translate with the

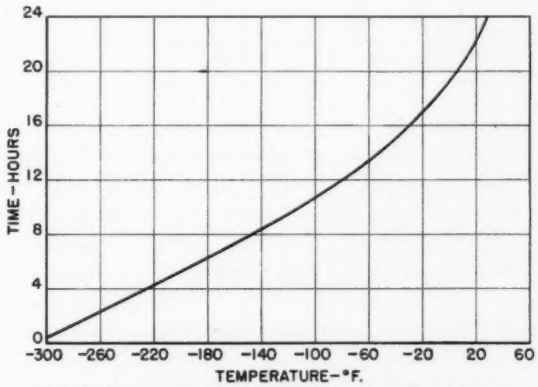


FIG. 3. TEMPERATURE OF COLD CHAMBER VS. TIME

supports of the beam, was not affected by the deflection of the beam and served as the zero sighting point for measuring the deflection. A reference cross on the side of the beam served as the movable target. With the load on and the load off the beam, the distance between the reference and the cross mark on the edge of the beam was noted. The difference of these two figures was taken as the absolute deflection caused by the load.

Method

The procedure was simple and straightforward. A gage was cemented on each face at the center of the beam with an acetate cement. A thermocouple was taped to the edge of the beam adjacent to the gages in an effort to secure as nearly as possible the exact temperature of the gages. With this placement, so that each gage acted as dummy for the other, one was tested in tension and one in compression simultaneously, and then the beam was turned over for the process to be repeated, thus checking both gages under two conditions with only two runs.

Fifteen liters of liquid oxygen were introduced from a container by air pressure (Fig. 2) into the jacket around the low temperature chamber just as rapidly as it would go without boiling out. About one hour was required for this procedure. The temperature, when reaching its lowest point, was found to stabilize and remain fixed for about 30 minutes while oxygen was still boiling within the jacket. Actually, oxygen could be heard boiling between the double walls for about 6 hours after it was introduced. When the temperature had stabilized, readings were made (1) of the temperature, (2) on an SR-4 Strain Indicator hooked into the circuit (Fig. 1), (3) on the galvanometer through the Wheatstone bridge, and (4) on the cathetometer. All these were made for load-on and load-off condition of the beam at intervals of about 10-degrees temperature rise. Since it required about 4 minutes for the temperature to rise one degree, and only about 40 seconds were required to make one set of readings, it was assumed that the temperature was steady state.

A small electric light bulb was inserted into the chamber to speed up the temperature changes as room conditions were approached, and also to carry the temperature on above room temperature in some cases. Another very small pen light bulb was focused on the edge of the beam to furnish illumination during the deflection reading. The small amount of energy introduced by this light proved to be of no consequence.

The cement used for the gages was tested in liquid oxygen for a period of time to determine its resistance to extreme temperatures, and was found to hold securely from subzero to a region of about 200° F. The strain indicator was also used as a check to make sure the cement had not broken at any time during the test.

RESULTS

All of the tables shown in this paper are only samples to illustrate the type of data recorded. Table I shows a sample of the data used as the basis for constructing the curve of the variation of the modulus of elasticity with temperature. Table

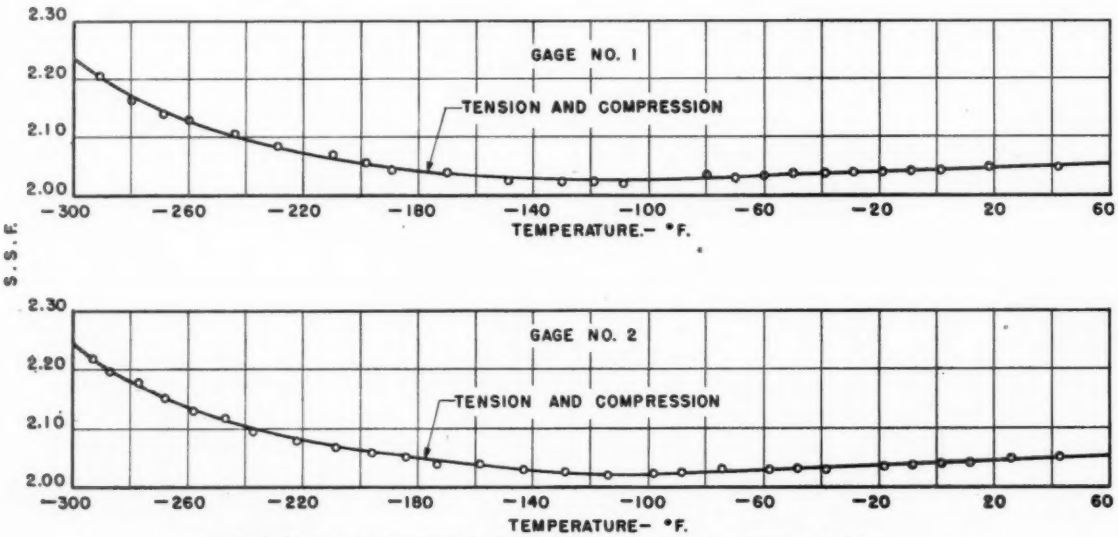


FIG. 4. STRAIN-SENSITIVITY FACTORS FOR NOS. 1 AND 2 OF TYPE A-1 GAGE

II includes the experimental data recorded for the determination of the change in resistance of the gages for each temperature. In the case of Table III, computation charts were utilized, but, since they were not deemed essential to the presentation of the method described here, they were omitted.

Although there are admittedly several possibilities for error inherent in the method used for this particular investigation, exhaustive trials of other methods indicated this one to be the easiest, most practical, and possibly the most accurate. It does not take into account, however, any possible rotation of the beam due to loading effects. Also, a deflection measurement using the supports for reference and loaded in this manner requires a consideration of shear deflection which in this case was calculated to be in the order of 1.19 by 10^{-5} in. and was considered negligible. The use of the deflection as found assumes the beam equation to obtain. Nonhomogeneity of the material could affect the response of the beam, causing a variance in the results obtained for tension and compression.

However, allowing for these and other sources of error, the work was carried on to obtain the results as seen in Figs. 4 and 5. Although in these curves some slight inconsistencies appear which may be attributed to the effects of the aforementioned errors, the trend of the behavior of the gages at low temperatures is definite. It will be noted that the gage factor determined by the manufacturer corresponds very well with that at near room conditions as determined by this method, tending to lend credence to those values found for other conditions.

The variance of the strain-sensitivity factor at very low temperatures from that at room conditions is in the order of from 6 to 8.5 per cent. It is quite significant that the change is so small for such extreme conditions which reach well below those for ordinary engineering applications. At a temperature as low as —200° F the change in almost every case is in the order of about 3 per cent from ordinary conditions. This would indicate that for accurate work it should be taken into consideration, but would not be too significant in most field work applications.

Other work remains to be done with an effort to eliminate as many sources of error as possible. This is being undertaken now with emphasis on above normal temperatures.

ACKNOWLEDGMENTS

The experimental work in connection with this paper was carried on with the able assistance of the writer's good friend and colleague, Major Ali Hakimet Sevand, who is now on active duty with his government in Istanbul. The importance of his contribution to the project cannot be overemphasized.

The writer further wishes to acknowledge his indebtedness and appreciation to Dr. W. M. Murray, Professor of Mechanical Engineering at the Massachusetts Institute of Technology, and Dr. Paul R. Shepler of Lessells and Associates, Boston, Massachusetts, for their assistance and advice.

Appreciation is also expressed to Massachusetts Institute of Technology and to the Turkish government for funds and material necessary for the completion of this work.

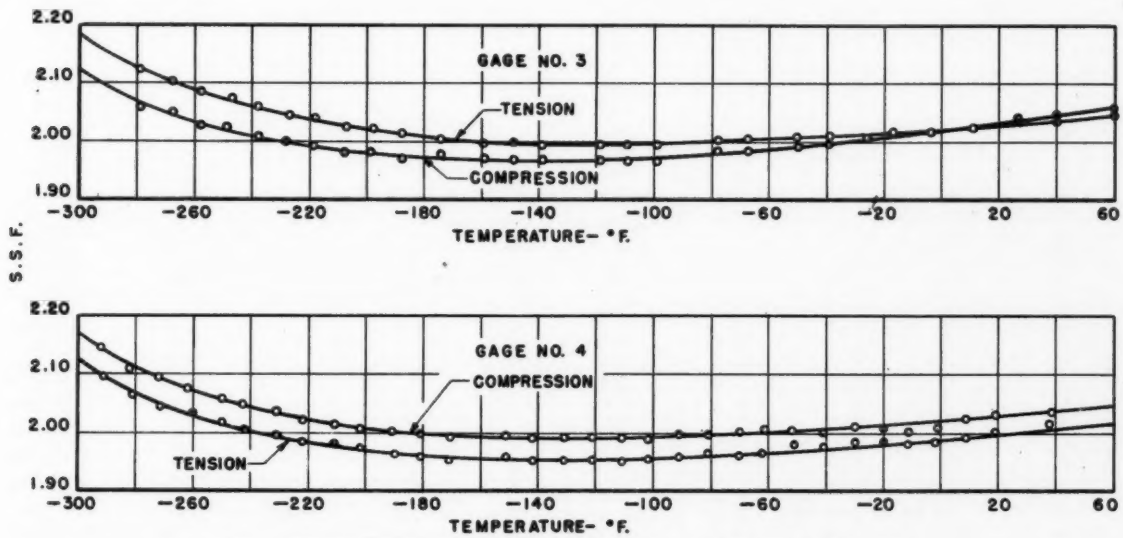


FIG. 5. STRAIN-SENSITIVITY FACTORS FOR NOS. 3 AND 4 OF TYPE A-5 GAGE

TABLE I

Temperature, Cathetometer Reading, and Modulus of Elasticity

Time	Temp. (°F)	UNLOADED			LOADED				
		Cathetometer Reading		Diff.	Cathetometer Reading		Diff.	Deflection (In.)	E Psi x 10^{-6}
		Wire	Beam		Wire	Beam			
5.35	−278	.2421	.9608	.2187	.7412	.8862	.1450	.0737	32.8
5.55	−273	.7412	.9602	.2180	.7416	.8859	.1443	.0787	32.8
6.20	−260	.7456	.9641	.2185	.7463	.8865	.1402	.0783	30.9
6.40	−251	.7436	.9633	.2197	.7460	.8849	.1389	.0808	30.2
6.50	−243	.7434	.9642	.2208	.7442	.8861	.1419	.0789	30.7
7.20	−228	.7442	.9643	.2201	.7434	.8865	.1431	.0770	31.4
7.35	−222	.7441	.9650	.2209	.7438	.8841	.1403	.0806	30.0
7.50	−221	.7446	.9661	.2215	.7436	.8855	.1419	.0796	30.4
8.10	−211	.7450	.9679	.2229	.7448	.8840	.1392	.0837	29.1
8.30	−207	.7461	.9685	.2224	.7453	.8850	.1397	.0827	29.3
8.45	−201	.7468	.9695	.2227	.7462	.8860	.1398	.0829	29.1
9.15	−196	.7465	.9695	.2230	.7466	.8857	.1391	.0839	29.8
10.10	−183	.7475	.9709	.2234	.7479	.8861	.1382	.0852	28.4
11.10	−171	.7490	.9725	.2235	.7497	.8880	.1383	.0852	28.4
12.10	−160	.7517	.9754	.2237	.7516	.8899	.1383	.0854	28.3
12.40	−154	.7514	.9752	.2238	.7512	.8898	.1386	.0852	28.4
1.10	−148	.7511	.9734	.2223	.7477	.8879	.1402	.0821	29.5
1.20	−141	.7508	.9713	.2205	.7492	.8871	.1379	.0826	29.3
1.35	−136	.7472	.9700	.2228	.7463	.8850	.1387	.0841	28.8
1.50	−131	.7442	.9662	.2220	.7433	.8822	.1389	.0831	29.1
2.30	−119	.7414	.9625	.2211	.7417	.8787	.1370	.0841	28.3
2.55	−110	.7407	.9612	.2217	.7395	.8769	.1374	.0843	28.7
3.15	−106	.7375	.9585	.2210	.7381	.8754	.1373	.0837	28.9

TABLE II

Bridge Readings A-1 Gage Nos. 1 and 2
S.S.F.=2.05

Time	Temp. (°F)	GAGE 1 (Tension)				GAGE 2 (Compression)			
		Load On		Load Off		Load On		Load Off	
		Decade Box R	Galv. R	Decade Box R	Galv. R	Decade Box R	Galv. R	Decade Box R	Galv. R
1.15	−283	118.7	+30.5	118.7	−8.0	118.6	−63.0	118.6	−26.0
1.45	−273	118.7	−5.0	118.7	−43.0	118.9	−78.0	118.9	−40.0
2.25	−263	118.8	+28.0	118.8	−11.5	119.0	−47.0	119.0	−9.0
3.00	−255	118.9	+27.5	118.9	−12.0	119.1	−48.0	119.1	−8.0
3.40	−235	119.1	+6.0	119.1	−32.5	119.2	+23.5	119.2	+61.0
4.20	−228	119.1	+74.0	119.1	+36.0	119.3	−12.0	119.2	+25.5
9.25	−197	119.5	−50.0	119.5	−88.0	119.6	−42.0	119.6	+3.0
9.55	−184	119.5	+21.0	119.5	−18.5	119.7	−55.0	119.7	−17.0
10.50	−157	119.7	+3.0	119.7	−36.5	119.8	+10.0	119.8	+49.5
11.55	−140	119.8	+31.5	119.8	−8.5	119.9	+33.0	119.9	+72.5
12.40	−130	119.9	−8.5	119.9	−48.5	120.0	−17.0	120.0	+22.5
1.10	−109	119.9	+31.5	119.9	−8.5	120.1	−74.5	120.1	−35.0
1.50	−96	119.9	+66.5	119.9	+26.5	120.1	−49.5	120.1	+0.0
2.25	−82	120.0	−12.0	120.0	−52.5	120.1	−15.5	120.1	+25.0
3.45	−69	120.0	+38.5	120.0	−2.5	120.2	−63.5	120.2	−23.0
4.30	−59	120.1	−72.5	120.1	−31.5	120.2	−40.5	120.2	+.5
5.15	−49	120.1	−18.0	120.1	−59.0	120.2	−26.0	120.2	+15.0
6.00	−89	120.1	−3.5	120.1	−44.5	120.2	−12.0	120.2	+29.5
7.05	−29	120.1	+17.0	120.1	−24.5	120.2	+4.5	120.2	+45.5
8.15	−13	120.1	+33.5	120.1	−8.0	120.2	+22.0	120.2	+63.0
9.30	+3	120.2	−47.0	120.2	−88.0	120.3	−59.0	120.3	−17.5
11.30	+25	120.2	−23.5	120.2	−65.0	120.3	−36.5	120.3	+4.5

TABLE III

COMPUTED RESULTS, TYPE A-1 GAGE NO. 1

Temp. (°F)	GAGE IN TENSION: From Table II $\frac{\Delta R}{R}$ ohms/ohm	GAGE IN TENSION: $\frac{\Delta L}{L}$ x 10^3	GAGE IN TENSION: Strain Sensitivity Factor (Gage Factor)	GAGE IN COMPRESSION: From Table II $\frac{\Delta R}{R}$ ohms/ohm	GAGE IN COMPRESSION: $\frac{\Delta L}{L}$ x 10^3	GAGE IN COMPRESSION: Strain Sensitivity Factor (Gage Factor)
−290	.3450	.1565	2.20	.3450	.1565	2.20
−280	.3460	.1593	2.17	.3460	.1593	2.17
−270	.3465	.1610	2.15	.3465	.1610	2.15
−260	.3470	.1630	2.13	.3470	.1630	2.13
−250	.3480	.1643	2.12	.3480	.1643	2.12
−240	.3485	.1660	2.10	.3485	.1660	2.10
−230	.3490	.1670	2.09	.3490	.1670	2.09
−220	.3500	.1683	2.08	.3500	.1683	2.08
−210	.3505	.1695	2.07	.3505	.1695	2.07
−200	.3512	.1705	2.06	.3512	.1705	2.06
−190	.3520	.1715	2.05	.3520	.1715	2.05
−180	.3528	.1720	2.05	.3528	.1720	2.05
−170	.3532	.1730	2.04	.3532	.1730	2.04
−160	.3540	.1735	2.04	.3540	.1735	2.04
−150	.3548	.1745	2.03	.3548	.1745	2.03
−140	.3555	.1750	2.03	.3555	.1750	2.03

(For bibliography, see page 32)

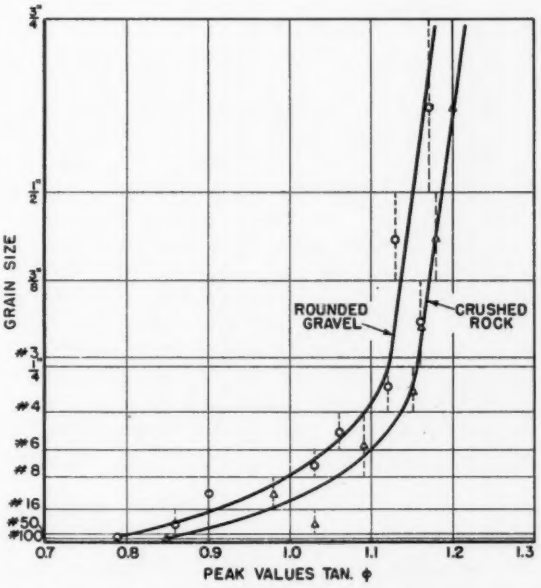
Tests for Shear Resistance Show Progress

The paper by G. Bryce Bennett, "Tests for Shear Resistance of Soils," which appeared in the July *Trend,* has been reprinted in *Highway Research Abstracts* for September, 1949, a publication of the National Research Council, and a request has recently been received for permission to reprint it in *Caminos y Calles* (*Roads and Streets*), a periodical widely distributed throughout Latin America. It therefore seems timely to present an improved version of his original graph in which results of further tests make possible a much more conclusive representation of the relationship between particle size and the peak friction values.

Since Mr. Bennett's graduation, work on this project continues through the efforts of Mr. Harold Mason, a graduate student in civil engineering. Another aspect of the investigation, dealing with clays, is being prosecuted by Mr. C. C. Wang, a research fellow in the Engineering Experiment Station.

Mr. Bennett's article dealt with the shear strength of sand of uniform particle size. Mr. Mason is extending the scope of this study to include the effect of grading, using a wide range of combinations of grain size. Mr. Wang's work concerns the effects of water content and film-water characteristics in determining the shear strength of clays. His test methods include liquid limit and unconfined compression tests at various ages of sample.

All phases of this study aim at establishing simple test procedures that will permit prediction of strength characteristics without the expense of direct measurement.



RELATIONSHIP OF GRAIN SIZE AND SHEARING RESISTANCE FOR GRANULAR SOIL

PHOSPHATE FERTILIZER BY THE FUSION OF PHOSPHATE ROCK AND OLIVINE

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R. W. Moulton

Introduction

The largest known deposits of phosphate rock, estimated at 60 per cent of the nation's reserves, are located in the Pacific Northwest, in the Montana–Idaho–Wyoming region. In 1943 these deposits furnished only about 5 per cent of the national production of phosphate rock. There is an increasing interest in the further development of these deposits because of the shortage of phosphate fertilizer in the western states.

Naturally occurring phosphate rock has little immediate fertilizer value when applied to the soil. The phosphorus content of the raw rock is not appreciably soluble in the soil solution and is, therefore, not readily available for assimilation in the growing process of the plant. The insolubility of the phosphorus in raw rock is usually attributed to the presence of fluorapatite ($CaF_2 \cdot 3Ca_3(PO_4)_2$).

The processing of rock for fertilizer purposes thus centers on the breaking down of the fluorapatite structure with the formation of more soluble phosphorous compounds. This may be accomplished by any one of several different methods. The bulk of the phosphate fertilizers being produced in the United States today are manufactured by acidulation.

In 1943 Walthall and Bridger[1] reported that by fusing phosphate rock with magnesia and silica, or with olivine, in the proper proportions, a phosphatic materially physically suited to fertilizer use was obtained with a phosphate content (per cent P_2O_5) of about 23 per cent, and that 94 per cent of this phosphate content was soluble in a citrated ammonium nitrate solution. This product compared favorably in total phosphate content and in available phosphate with ordinary superphosphate. It also contained soluble magnesia which would be desirable when it was used as a fertilizer in areas showing magnesia deficiency. The availability of phosphate rock, olivine, and low cost electric power in the Pacific Northwest suggested that such a process would probably have commercial significance in this region and prompted the investigation carried on during 1946-47 by the Chemical Engineering Department in cooperation with the Bonneville Power Administration which supplied funds for research fellowships and equipment. G. S. Greaves, Research Fellow, assisted the writer in the work described in the following pages.

The only other published work dealing directly with this problem was that of Fasting and Haraldsen,[2] who fused and calcined mixtures of phosphate rock with magnesia, silica, and/or olivine and determined the structure of their product by X-ray techniques. They concluded that the magnesia tended to stabilize an insoluble form of phosphorus.

Although magnesium has been recognized and classed as one of the secondary plant nutrients since about 1920 and many different papers have appeared on methods for incorporating this element in fertilizer, most of these methods involve reaction in water solution or addition of magnesia-containing substances as "aging" agents to superphosphate. Typical is the report of Druzhinin[3] in which dunite is added to superphosphate.

EXPERIMENTAL PROCEDURE

Raw Materials

The phosphate rock used in all the fusions described in this paper was obtained from a deposit near Garrison, Montana; the olivine from the Twin Sisters' deposit to the southeast of Bellingham, Washington. Both materials were prepared for use by grinding to pass a 65-mesh screen. An analysis of representative samples appears in Table I.

TABLE I — COMPOSITION OF RAW MATERIALS
(Composition per cent by weight)

Material	P_2O_5	CaO	MgO	SiO_2	R_2O_3	SO_3	F	Ig Loss
Rock Phosphate	31.3	43.7	0.4	13.7	4.2	0.4	3.4	1.9
Olivine	....	0.0	48.5	42.0	10.4	....	....	0.4

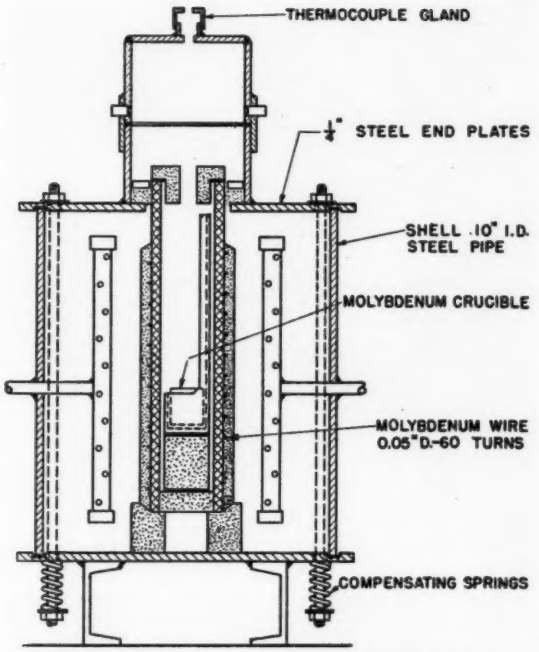

FIG. 1. MOLYBDENUM WOUND TUBE FURNACE

Equipment

A consideration of the various means available of obtaining the desired temperature necessary for this work led to the choice of a molybdenum resistance wire tube-type furnace as being the most suitable. In this type of furnace the wiring must be protected by means of an inert atmosphere containing no oxygen.

A drawing of this furnace as constructed is shown as Fig. 1. The winding was designed to operate on 220 volts and at this voltage developed about four kilowatts. This power supply was ample to meet all of the desired operating conditions.

During this work the furnace was maintained at temperatures above 1300° C for approximately 120 hours without failure. The furnace performance was satisfactory in all respects.

All temperatures were obtained with an optical pyrometer calibrated by comparison with a platinum–platinum-rhodium thermocouple. The two readings agreed within 5° C over the temperature range 800° to 1400° C.

One of the most difficult problems encountered in the earlier phases of this investigation was that of obtaining a satisfactory material for containing the molten charge. The crucibles tested were subjected to the requirements of being nonreactive with the melt, nonabsorbent, and resistant to thermal shock.

The following materials were tested and found unsatisfactory: alundum, graphite, and zirconia. Molybdenum, the material decided upon for the crucible, proved satisfactory for this work. The crucible, which was manufactured by Callite Corporation from the powdered metal, was used for about 75 fusions, representing exposure to molten phosphate at temperatures up to 1750° C for about 15 hours. After this severe treatment, the crucible was still in good condition and could be utilized for many more runs.

Procedure

The finely ground raw materials, dried at 105° C, were weighed in the desired proportions, intimately mixed, and charged to the crucible. The capacity of the crucible was about 12 grams of charge. The crucible and contents were inserted into the furnace by means of a graphite holder. The charge was fused for the desired length of time, removed, and poured immediately into the quenching unit.

The charge usually began to fuse about 2½ minutes after being placed in the furnace. This fusion was characterized by the vigorous evolution of gases. After gas evolution was complete, the melt remained quiescent and clear. Several observations revealed that the completion of fusion of the charge was indicated by the completion of the gas evolution. Consequently, the time at which the gas evolution was complete was taken as zero time of fusion in the time measurements. Temperatures reported here were those taken just before the melt was taken from the furnace.

It was learned early in this work that the melt must be rapidly cooled to or near room temperature if a high degree of phosphate availability was to be attained in the final product. To insure the elimination of possible deviations in results because of this quenching effect, a simple but effective quenching system was designed. This quenching apparatus was essentially a high velocity stream of water which both disintegrated and cooled the melt. The quenching was so rapid that the quenched material would fracture under the internal stresses developed during the quenching for up to three hours after its removal from the water.

The final product was composed of small, hard spheres and spherical fragments, black to dark brown in color. Under the microscope these particles appear glassy and semi-transparent (Fig. 2).

Method of Analysis

As the substance under study differs in method of manufacture, structure, and composition from other phosphate fertilizers now on the market, the best method for measuring its fertilizer efficiency

required a basis affording comparison with other types of phosphatic fertilizers. Two methods, both based on solvent extraction, but differing in the solvent used, are authorized by the Association of Official Agricultural Chemists[4] in determining the available phosphate content of fertilizers. For the "Thomas" or basic slag-type phosphates, a 2 per cent citric acid solution is prescribed as a solvent, whereas a double extraction using water followed by a neutral ammonium citrate solution is used for other types.

As the product of these fusions is logically classed as a slag-type fertilizer as differentiated from wet processed materials such as superphosphate, the 2 per cent citric acid solvent, it seemed, should yield results more indicative of the actual efficacy of the product.[4] This view is substantiated by the correlations on actual plant growth obtained by Ross and Jacob[5] in their studies of a physically similar material, fused phosphate rock. The analyses for available phosphate reported in this work were all made using this latter method.

DISCUSSION OF RESULTS

Effect of Composition on Raw Materials

A series of fusions in which the olivine to rock phosphate ratio was varied was conducted in a furnace atmosphere of hydrogen using a molybdenum crucible. Practically 100 per cent phosphate availability was attained by fusing a mixture containing 16.7 per cent olivine, whereas the previous investigators required an olivine content of about 35 per cent to achieve this solubility. The results of the fusions made with a nitrogen atmosphere showed that the olivine content in the initial charge required to produce 100 per cent phosphate solubility in the quenched melt is about 26.5 per cent, a value lying between that obtained from our fusions in hydrogen and that given by Walthall and Bridger.[1]

The consistency of the data within each series indicated the existence of a variable common to each series, but differing in degree. A comparison of the phosphate content of the melt with other constituents resulted in the correlation shown in Fig. 3. From this standpoint, the phosphate solubility is directly related to the SiO_2/P_2O_5 ratio in the final product. Data of Walthall and Bridger[1] substantiated the relation obtained.

Obviously, in the data presented thus far, a relation similar to that shown in Fig. 3 will be obtained by consideration of the mol ratio $MgO/_2O_5$ as the independent variable. Certainly, under the conditions of these experiments, the individual effects of MgO and SiO_2 on the conversion process cannot be divoreed. Fig. 3 must not, then, be construed as presenting the action of SiO_2 alone on the conversion of phosphate to the citrate soluble form.

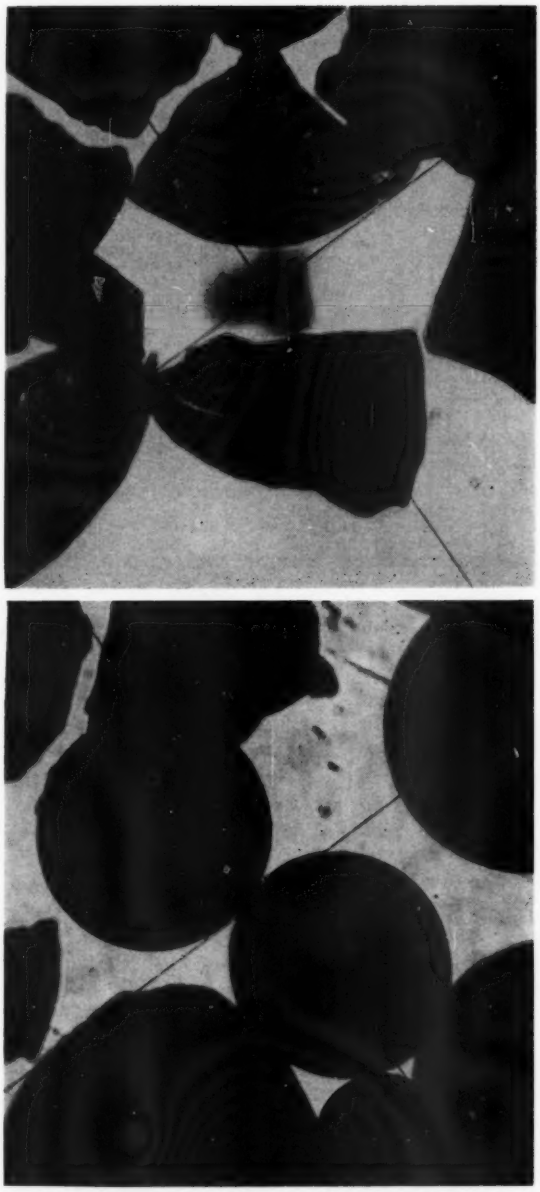

FIG. 2. PHOTOMICROGRAPHS OF QUENCHED PRODUCT (x 100)

After the review of the range encountered in the other variables (time and temperature of fusion, composition of raw materials, and F and P_2O_5 volatilization), one is led to the conclusion that the correlation experienced in Fig. 3 is not coincidental. In combination with information presented

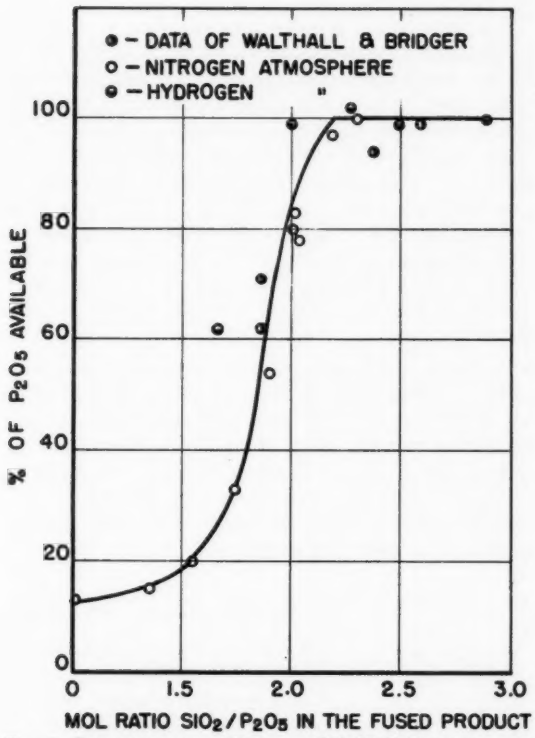

FIG. 3. CORRELATION OF DATA BY SiO_2/P_2O_5 RATIO IN THE FUSED PRODUCT

and discussed later in this paper, this initial observation of the dependence of phosphate solubility on the composition of the final melt aids in formulating an explanation of the nature of the conversion action.

It is apparent that the optimum ratio of olivine to be used in a given fusion cannot be directly defined. Rather, the most favorable mixture of raw materials to be used must be defined in terms of the final product composition which, as will be seen, can vary over a considerable range.

Effect of Time

In order to determine the dependence of phosphate solubility on the fusion time of the melt, fusions were made for various lengths of time. As previously mentioned, zero time of fusion was taken as the time when the complete charge had just fused, signified by the complete evolution of gases from the fusing melt. In most runs it required about five minutes to reach this point. Temperature effects were reduced to a minimum by so regulating the furnace temperature and, consequently, the heating rate, that practically all melts were removed from the furnace at or near the same temperature (1490° C, ± 3%).

The soluble phosphate content of the quenched melt was found to be practically independent of the time the melt is held in the fused state. Increase in solubility, then, results from changes taking place during the time the material is being fused.

Effect of Temperature

It is well to introduce this section by reviewing the temperature history of a charge from insertion in the furnace to removal from quench water. About 2½ minutes were required for preheating the charge. Another period of time of about the same length was required for fusing the charge. The time the charge was held in a molten condition in a furnace was variable. It was estimated that about two seconds were required to transfer the molten charge from the furnace to the quench water. The water quenching was rather rapid, taking only a fraction of a second.

The following two conditions which complicate any studies of the temperature variable are apparent:

1. The constant variation of temperature with time necessitates the choice of some arbitrary value of temperature as a basis for purposes of comparison.
2. The charge is not quenched (water quenched) at the maximum temperature attained during fusion.

Of these, it is believed that the second condition is the more pertinent as it is entirely possible that variations of phosphate availability may be a function of the quenching temperature of the melt.

That the temperature on removal from the furnace and the temperature at which the melt first struck the stream of water were not the same was a result of cooling in air during the short but definite time required to remove and pour the charge. This time was about two seconds and could not be further reduced with the particular procedure used in these experiments. The comparatively slow rate of cooling in air does not permit the designation of this period of cooling as quenching in the

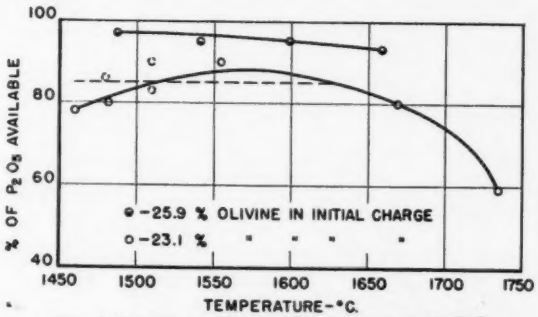

FIG. 4. EFFECT OF FUSION TEMPERATURE ON P_2O_5 AVAILABILITY

sense used in this discussion. The quenching temperatures were estimated to be from 100° to 200° C less than the temperatures determined at the end of the fusion, the larger value applying to the higher temperature runs.

The results of the temperature studies are shown in Fig. 4. The temperatures reported are those attained by the charge just before removal from the furnace. Some average value over the time the charge was molten might as well have been selected; however, the final temperature is believed to be more significant.

The time of fusion was held within 1½ minutes of 10 minutes for all runs. Earlier work showed that 10-minute fusions were sufficient for these experiments.

The curve representing 25.9 per cent olivine in the initial charge showed little variation of phosphate availability with temperature. The curve showing the results of the runs made with 23.1 per cent olivine in the charge showed a large decrease in phosphate availability above 1600° C.

Fusions with Magnesia and Silica

In order to extend the range of product composition, fusions were conducted in which the ratios MgO and SiO_2 to P_2O_5 were different from those obtainable with olivine as the addition agent. Magnesia (C.P.) and silica (C.P.) were mixed with phosphate rock to give the desired product compositions. Fusion time was held at 10 minutes. Temperature at the end of fusion was maintained at $1480 \pm 10°$ C for one group of fusions and at $1530 \pm 10°$ C for the remainder. The higher temperature was necessitated by the higher melting points of many of the fusions in this group.

Ternary presentation was considered the most suitable method for illustrating the combined effect of MgO and SiO_2. The data of Walthall and Bridger,[1] together with data from other runs reported previously in this paper, were calculated to a molar basis and are presented on the ternary diagram, Fig. 5. The correlation thus obtained appears to be quite satisfactory.

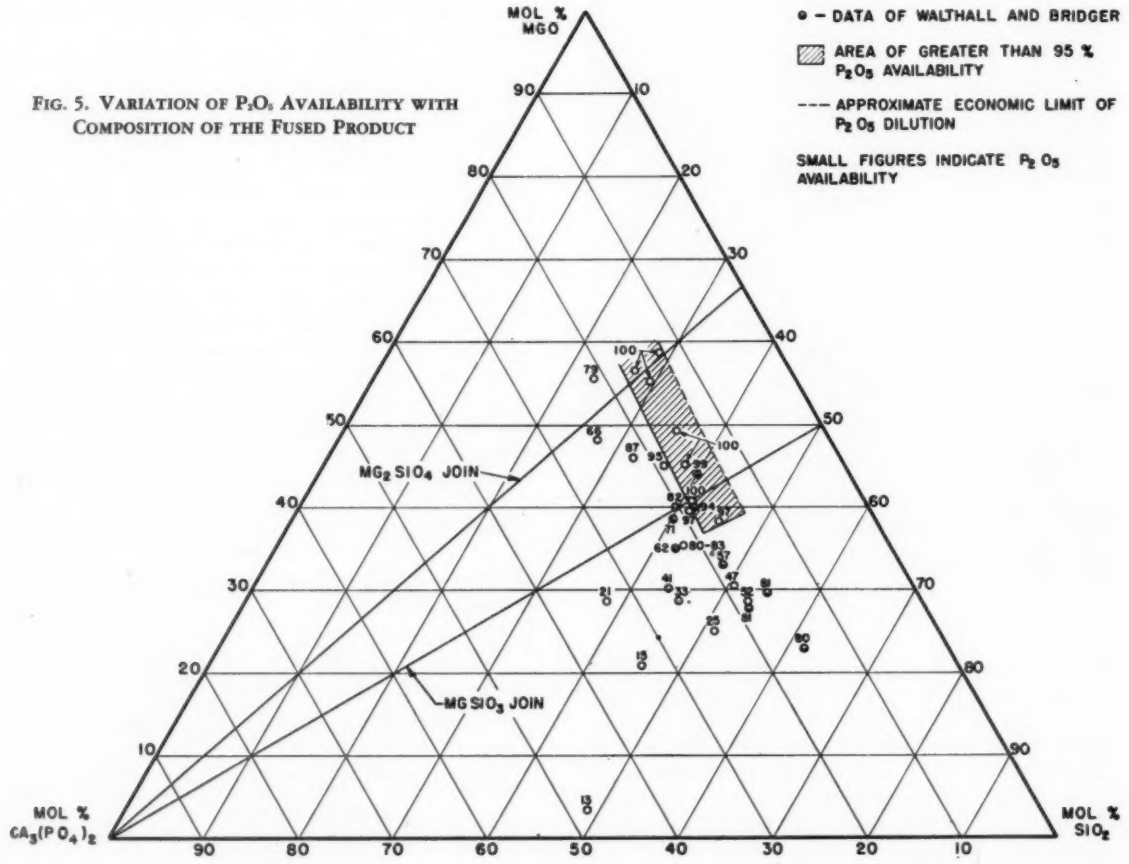
MOL % MGO
MOL % $CA_3(PO_4)_2$
MOL % SiO_2
MG_2SiO_4 JOIN
$MGSiO_3$ JOIN
● – DATA OF WALTHALL AND BRIDGER
AREA OF GREATER THAN 95 % P_2O_5 AVAILABILITY
--- APPROXIMATE ECONOMIC LIMIT OF P_2O_5 DILUTION
SMALL FIGURES INDICATE P_2O_5 AVAILABILITY

FIG. 5. VARIATION OF P_2O_5 AVAILABILITY WITH COMPOSITION OF THE FUSED PRODUCT

In evaluating the information in Fig. 5, the following points should be kept in mind:

1. All of the P_2O_5 is represented as being in combination with calcium, which may or may not be entirely accurate.
2. The presence of other constituents, such as FeO, Al_2O_3, and F, are not indicated; certainly, it is possible that any or all of the many elements present in the complex system of the quenched melt may influence its P_2O_5 solubility. That this influence is negligible or a constant factor is a necessary assumption.
3. Only that CaO assumed to be combined with P_2O_5 as the tertiary orthophosphate is included in the plot. The CaO in excess of this requirement was practically constant at 0.5 mol per mol of P_2O_5 in all the fusions of this work. The excess CaO in Walthall and Bridger's fusions varied because of differences in P_2O_5 volatilization.

In the utilization of fusion products as fertilizers, there is an economic limit of the dilution of the P_2O_5 content with addition agent (about 20 per cent P_2O_5 by weight). Investigations, therefore, were limited to dilutions above this minimum P_2O_5 content, approximately indicated by the broken line in Fig. 5.

Based solely on P_2O_5, MgO, and SiO_2 content of the quenched melts which contain 20 per cent by weight or more P_2O_5, there is apparently a definite range of compositions in which P_2O_5 solubility of 95 per cent or better is attained. This area of high availability can be defined by four terminal points of the following molar ratios:

$\frac{MgO}{P_2O_5}$	$\frac{SiO_2}{P_2O_5}$	$\frac{MgO}{SiO_2}$
3.3	1.4	2.4
5.0	2.3	2.2
1.9	2.3	0.8
3.1	3.6	0.9

SUMMARY

The following conclusions can be drawn as the result of this work:

1. By completely fusing phosphate rock with the proper proportions of magnesia, silica, and/or olivine and then shock-cooling the melt in a high velocity stream of water, a material is obtained in which 95 per cent or more of its P_2O_5 content is soluble in a 2 per cent citric acid solution.

2. Achievement of P_2O_5 solubility is a function only of the composition of the final product if properly quenched. Products containing at least 20 per cent by weight of P_2O_5, which is 95 per cent or more soluble, lie within an area defined by the mol ratios *in the product* at the terminal points:

$\frac{MgO}{P_2O_5}$	$\frac{SiO_2}{P_2O_5}$
3.3	1.4
5.0	2.3
1.9	2.3
3.1	3.6

CaO in a ratio of at least 3 mols per mol of P_2O_5 and about 1 mol per mol of fluorine content *in the product* is assumed. In calculating mixtures of raw materials to attain the desired composition of product, P_2O_5 loss by volatilization should be considered.

3. The time the melt is held in the fused state, in fusions of olivine and rock phosphate, has no appreciable effect on P_2O_5 availability. A slight decrease in availability may be obtained in 1 to 3 minutes after the system is completely fused.

4. The temperature attained by melts of phosphate rock and olivine has no appreciable effect of P_2O_5 availability in the range 1450-1600° C. Above 1600° C a decrease in solubility may occur, the decrease increasing with temperature.

5. Volatilization of P_2O_5 from the melt is not evident in the absence of reducing substances (carbon and hydrogen) either at long fusion times or temperatures up to 1740° C.

6. Fluorine in excess of about 0.56 per mol of P_2O_5 in the melt is volatilized during the fusion. Fluorine volatilization is dependent on the P_2O_5 (and possibly alumina) content of the melt and is not increased by long fusion times or temperatures up to 1470° C. Volatilization in excess of that represented by the mol ratio 0.56 occurs in an atmosphere of hydrogen and, in some instances, in highly siliceous melts.

7. In the slags of 100 per cent P_2O_5 solubility, the magnesia and fluorine are both 100 per cent soluble in 2 per cent acid.

8. Two per cent citric acid solution is suggested as a solvent for determining the "availability" of the magnesia content of the product.

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DYNAMIC DESIGN OF BITUMINOUS PAVEMENTS

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Research Fellow in the Engineering Experiment Station

ROBERT G. HENNES
Professor of Civil Engineering

H. H. Chen

The greatly expanded postwar program of highway construction has benefited from accelerated research in constructional materials. In the field of bituminous surfaces emphasis has been placed on stability of the paving mix. The sharp interest in stability testing does not spring from difficulty in making a stable road surface, i.e., a pavement which can sustain ordinary wheel loads without excessive deformation. Without much help in the way of laboratory control, any experienced highway engineer can design a bituminous mixture which will stand up under traffic, and which will cost no more than a weak pavement. Too often, however, such roads eventually break up under exposure to extreme temperatures or prolonged wet weather. The problem is to incorporate enough asphalt into the mix to provide durability, without adding so much asphalt that the pavement is soft. *Permanent* stability is best assured by careful laboratory control of the mix.

It is noteworthy that all generally accepted test methods for predicting asphalt pavement performance are concerned with the ultimate strength characteristics of the mix. Sometimes these are expressed in terms of friction and cohesion, sometimes in terms of more arbitrary coefficients or indices. Rather commonly, the design of pavement thickness is a process which does not involve the actual use of such test data; either the selection of a value for thickness is based upon its empirical correlation with wheel load and subgrade characteristics, or it is computed by means of one of several available punching shear formulas. Incidentally, perhaps the most comprehensive treatment of the latter procedure is still available as Engineering Experiment Station Bulletin No. 83 by the late Professor George Hawthorn.

All of the above analyses are concerned with the pavement in a state of plastic equilibrium. Their results are expressed in, or can be reduced to terms of ultimate shear values, or are based upon such values. This preoccupation with a stress condition that the engineer wishes to avoid, to the exclusion of any consideration of the state of stress actually present in the functioning pavement, stems from the realization that the asphalt is a liquid, without static strength in shear or tension. *The traffic lane is designed as a parking strip.*

R. G. Hennes

In reality, the viscosity of the bituminous binder does endow the pavement with dynamic resistance to shear and tension that enables it to act as an elastic slab under moving wheel loads. Given the necessary measurements of these dynamic properties, it should be possible to design bituminous pavements by the same methods that have been used with Portland cement concrete.

Westergaard's formula for pavements relates thickness to external load, flexural stress, modulus of elasticity, and Poisson's ratio. When solving for thickness, the stress is taken as some specified percentage of the modulus of rupture. The literature on the subject did not show any precedent for our present attempt to evaluate the dynamic modulus of elasticity and modulus of rupture for a bituminous paving mix. However, vibrosonic technique had received wide acceptance in concrete testing, and the apparatus was available for the present investigation of dynamic E for asphalt mix.

Vibrosonic tests make use of the relationship which exists between the resonant frequency of the test specimen and its size, density, and modulus of elasticity. The specimen is caused to vibrate at different frequencies until resonance is attained. If the other physical characteristics of the specimen are known, and the resonant frequency has been observed, the modulus of elasticity can be computed. The writers, who were unable to locate previously recorded data to check or conflict with theirs, generally found the resonant frequency to be below 200 cycles per second. Unfortunately, this is a range in which resonance in parts of the apparatus itself becomes troublesome. This factor is

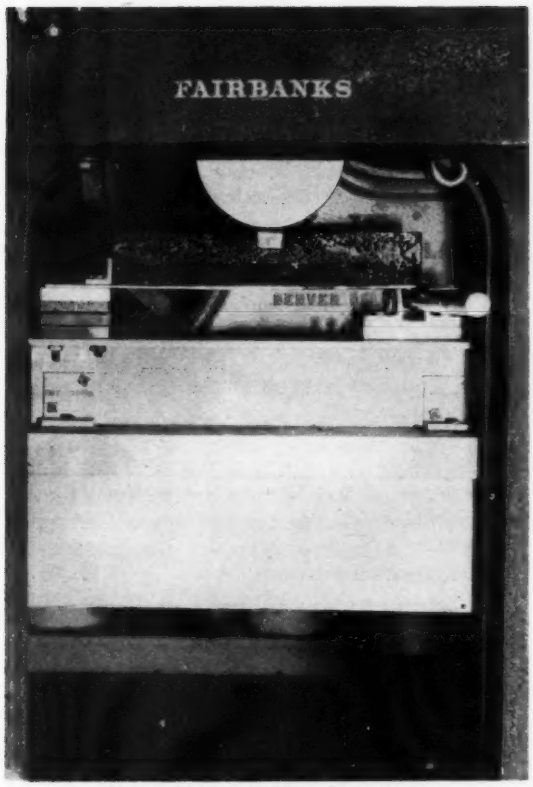

FIG. 1. FLEXURAL TEST APPARATUS

under investigation at present, and some of the earlier findings may need modification. The computed values of E, around 30,000 psi, check well with static tests reported by W. Hillman* in 1940; but this agreement between static and dynamic measurements can hardly be considered as a confirmation of either finding. While any concept of a modulus of elasticity under static loads can hardly apply to bituminous mixtures, it seems reasonable to assume that a dynamic modulus of elasticity obtained from a test that offers little opportunity for plastic deformation because of rapid reversals in stress, does express the stress-strain relationship that would prevail in a pavement subjected to transient wheel loadings.

Specimens for both the vibrosonic and the flexural tests were asphaltic concrete beams, measuring 2 by 2 by 12 in. Among other considerations which dictated this selection of specimen shape, one is noteworthy: the fact that the rectangular beam is superior to the cylindrical specimen with respect to ease in simulating actual field compaction methods. Instead of being compacted by tamping or by direct compression, the beams were rolled in two layers, presumably producing a proper orientation of the particles of aggregate. The compacted specimens contained 4 per cent air voids. Aggregate was a carefully graded crushed rock with a maximum size of ½ in. The mix included 6.65 per cent of 85-100 penetration asphaltic cement.

How to measure the modulus of rupture was a problem which was further complicated by the necessity for improvising a dynamic test procedure. Any static load would cause plastic flow, and any ordinary method of gradually increasing the test load up to the breaking point would require time enough to involve the same error. To circumvent this difficulty, the beam was laid upon a spring steel leaf (2 by 3/16 by 16 in.) fixed at one end, and supported at the other from a 500-pound capacity Fairbanks scales. The spring was designed to simulate the elastic action of an average subgrade in restoring the surface of the pavement to its original position after each transient loading. The beam was subjected to 37 flexures (and rebounds) per minute by means of a rotating eccentric disc in continuous contact with the midpoint of the beam (Fig. 1). This repetitive loading was continued without interruption until fracture occurred. The magnitude of the reaction at the simply supported end of the beam was read from the scale. The portion of the reaction carried by the steel leaf was estimated, for specific eccentricities of the loading disc, by replacing the asphalt beam with a short wood block of equal thickness, and reading the reaction on the scales. The average net value of the reaction was used to compute the bending moment at the midpoint of the asphalt beam and, subsequently, the modulus of rupture which corresponded to the observed number of repetitions of load at failure. This, of course, was essentially a fatigue test. By repeating this procedure on similar specimens but with different eccentricities of

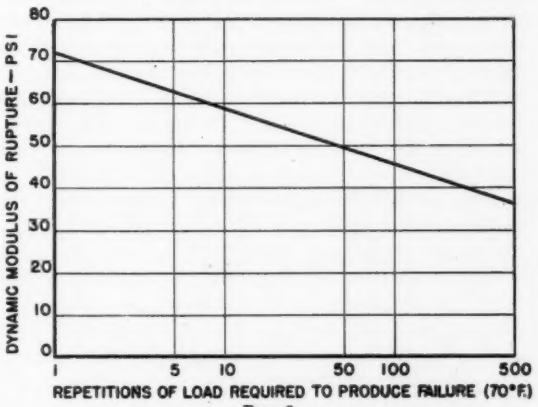

FIG. 2

* *Public Roads*, Vol. 21, No. 4 (June, 1940), p. 69.

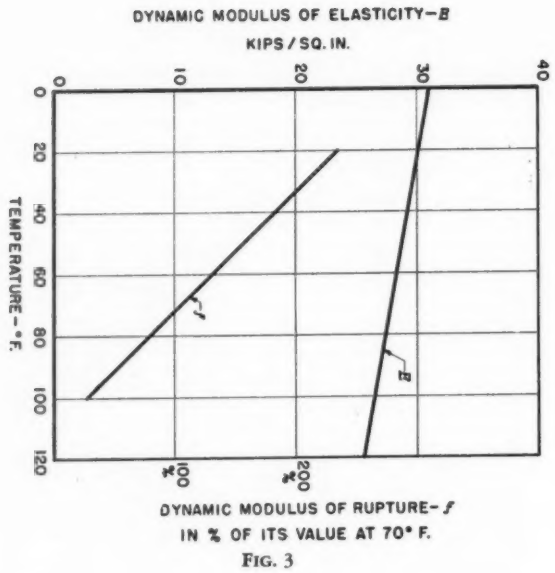

FIG. 3

the rotating disc the data were obtained which permitted the plotting of Fig. 2, in which the modulus of rupture is expressed as a function of the frequency of load application. The sole purpose of this operation is to find, by extrapolation, the modulus of rupture corresponding to a single load application. Actually, fatigue is not a factor in bituminous pavements because the failure of wheels to follow the same track produces a kneading action which revivifies the paving.

Temperature is a major factor in the elastic behavior of bituminous surfacings. Since it was not possible to vary testing room temperatures to the extremes encountered in the field, the effect of temperature was evaluated by storing specimens overnight in an oven or in the freezing room; then testing them after predetermined periods of exposure to room temperature (70° F). Control specimens with imbedded thermometers were similarly handled, and their carefully noted time rates of cooling or warming in the testing room were assumed to apply to the test specimens with sufficient accuracy for the purpose. Fig. 3 shows the effect of temperature on the observed values of the moduli of elasticity and rupture. In both cases the variations are attributed to changes in the viscosity of the asphalt. It may well be that E varied less with temperature in these tests than it would in an actual pavement, if it be agreed that resistance to tension originates in the ductility of the asphalt films. Even with fast traffic, the rate of stress reversal in the pavement is well below the resonant frequency of the test beams, and on the other hand might exceed the rate of repetitive flexure in the bending tests. In either case, the amount of viscous resistance to dynamic loading is reflected in the actual stress intensity, whether this is computed from laboratory data or is measured on the prototype. Consequently, the results graphed in Figs. 2 and 3 should be taken to indicate trends, rather than regarded as set values.

A third elastic constant, Poisson's ratio, was computed from the volumetric change experienced by a 4-by-8 cylindrical specimen when subjected to axial compression. The value obtained was 0.2. Undoubtedly, a dynamic test method would have been preferable, had a suitable procedure been available.

The Westergaard equation for stress in the interior of a paving slab is

$$\sigma = 0.275\, Ph^{-2}\,(1+\mu)\,\log_{10}\,(Eh^3\,k^{-1}a^{-4})$$

The terms in this formula are assigned the following values for the purpose of an illustrative problem:

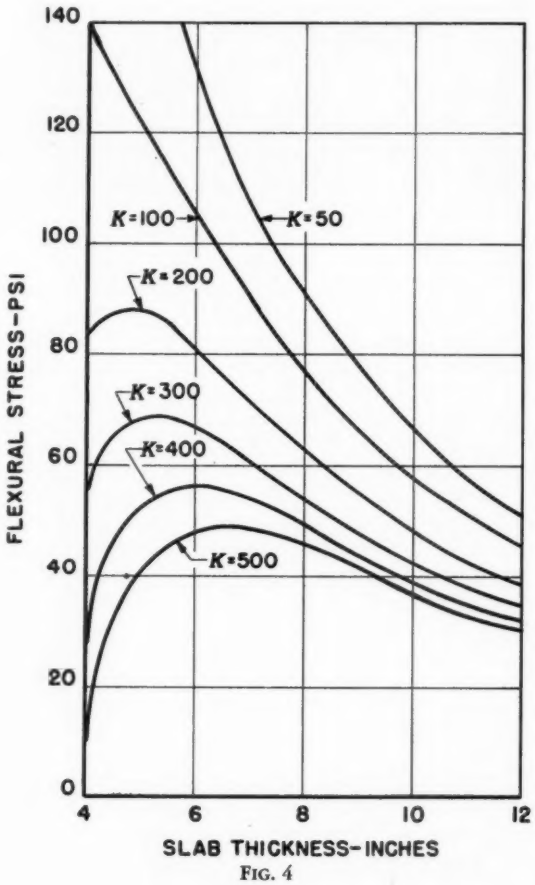

FIG. 4

σ=flexural stress in psi
P=wheel load of 9,000 lbs.
μ=Poisson's ratio, 0.2
E=modulus of elasticity, 28,000 psi
h=required pavement thickness in inches
k=modulus of subgrade reaction in pounds per cubic inch
a=radius of tire contact, 7½ inches (assuming a tire pressure of 50 psi)

The solution of this equation is shown in Fig. 4. On a soft subgrade (k=50) substantial thicknesses of bituminous surfacing are required for the low moduli of rupture prevailing in hot weather. However, if a macadam base is used (k=500), the required thickness is in reasonable accord with the values found in present practice. In other words, high-type asphaltic concrete pavements do function as elastic slabs. For low values of h the basic equation may need modification because of the relatively high value of a in that range.

Because of the low moduli of elasticity the required thickness of bituminous surfacings is more directly related to the quality of the subgrade than is the case with Portland cement concrete. Fig. 5 shows the required slab thicknesses for both asphalt and concrete pavements, expressed as percentages of the thicknesses required for a k of 100. The need for base courses in bituminous construction is apparent.

The investigation reported above has not yet developed a wholly satisfactory method of bituminous pavement design. Considerable work has yet to be done on test methods, and on a study of the validity of existing equations in this range of elastic behavior. Even then, something of the conventional stability approach must be retained for static loadings. On the other hand, the feasibility of a dynamic design procedure is now evident. The selection of test methods which permit use of a rectangular beam for the test specimen is a matter of no little importance. There is a growing body of evidence, reported elsewhere, that the simulation of field compaction methods is the primary laboratory problem in testing of bituminous mixtures. A test

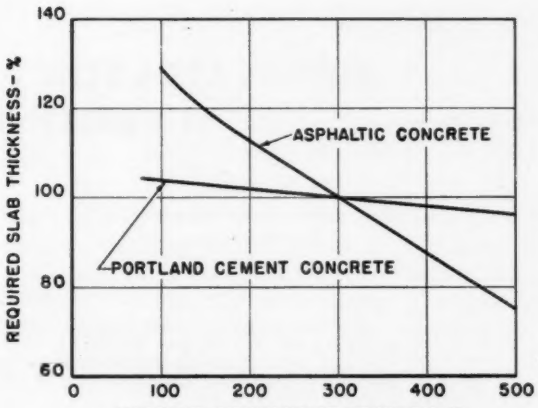

FIG. 5

specimen which can be compacted by rolling has great advantage. It may be that the 2-by-2-by-12 in. specimen could be improved by increases in its width and length; that the dynamic modulus of elasticity could be measured better by methods which did not involve resonant frequency; and that the dynamic modulus of rupture could be found more conveniently by a strain-control mechanism that did not depend upon repetitive loading. These possibilities are being investigated. Progress reported in this paper does appear to demonstrate that bituminous pavements can function as elastic slabs, and to indicate the desirability of design procedures that take into account the state of stress in which actual pavements actually function.

It is interesting to note that in recognizing the need for both stability and flexural tests as a basis for design, the present investigation comes, by a completely different approach, to a conclusion previously reached by Francis Hveem of the California Department of Highways.

The work described has been carried on as a part of Engineering Experiment Station Project No. 6. Ching C. Kuan, Research Fellow in 1948, conducted much of the preliminary study and laboratory work. The writers continued the work and brought it to its present stage in 1949.

ROAD BUILDERS TO MEET

The Third Northwest Conference on Road Building will be held in More Hall February 6-7-8, 1950. The meeting is expected to attract over three hundred engineers from Washington and adjoining areas. Among the speakers who have accepted invitations are W. A. Bugge, Washington Director of Highways; Joseph Barnett, Chief of Urban Design, Bureau of Public Roads, Washington, D.C.; K. B. Woods, Director of the Joint Highway Research Project, Indiana; N. R. McKay, R. P. Newland, and Lloyd Morgan of the Washington State Highway Department; Bryce Bennett, Idaho Highway Department; Homer Hadley, consulting engineer; Joseph Holt, expert on steel straightening; Prof. R. H. Meese, University of Washington. Interested engineers are invited to write for a program.

The *Proceedings* of the 1949 Conference are still available at $1.00.

ORDINATES FOR AXIALLY SYMMETRIC SUPERSONIC NOZZLES*

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SUMMARY

The semi-graphical integration method proposed by Sauer[1] is extended and used for the determination of ordinates for axially symmetric supersonic nozzles for Mach numbers of 3.15 and 5.49. A comparison is made between these ordinates and those obtained through use of the more approximate method of Foelsch.[2]

D. W. Lueck

The University of Washington Aeronautical Laboratory Supersonic Tunnel No. 1 currently employs two - dimensional nozzle blocks to obtain a Mach number of 3 in a 3 by 3-in. rectangular test section. Studies were begun in the autumn of 1947 into the design of an axially symmetric nozzle to be used with the Tunnel No. 1 power system for the production of a circular open-jet test arrangement.

The boundary of a supersonic nozzle is found from the integration of the characteristic equations of the flow. In the case of axially symmetric flow an exact integration of the equations cannot be made by analytical methods. Sauer[1] in 1940 proposed a semi-graphical integration by successive approximation which, although lengthy, can be carried to any desired degree of accuracy. The flow in the mid-section of the rotationally symmetrical nozzle is radial and is confined within a cone whose apex angle is limited by the critical expansion angle for the test section Mach number.

The transition from the sonic throat to the conical expansion section, which can be represented by any convenient monotonically increasing function of area, is required only to produce the radial flow at the entrance to the conical section. It is then possible to suppose the flow as emanating from a source at the virtual apex of the conical section. The third section of the nozzle is the transition curve which converts the radial flow into uniform, wave-free, parallel flow at the desired Mach number. It is the function of this latter transition to cancel all approaching expansion Mach waves and hence put an end to the velocity increase.

A. J. Wang

Determination of a nozzle boundary by the method of characteristics requires the assumption of some initial flow pattern. If the flow velocity is assumed to be constant on an arc through the sonic point with the arc center at the apex of the cone, then the direction of the flow is radial from the apex. Using these initial conditions, stepwise integration of the characteristic equations is used to establish the characteristic lines (which are actually the Mach lines) in the conic section. Once the pattern of Mach lines in the conical section is established it is required of the following Mach lines that they have such a direction that they will tend to turn the flow into a direction which is parallel to the axis of symmetry. The nozzle contour in the transition region is then determined by the condition that the boundary must be parallel to the adjacent flow. The directions of the velocities are known when the Mach pattern is known. The essence of the problem is then to determine the pattern of Mach lines beginning with the radial flow and ending with wave-free, parallel flow at the test section.

In the simple case of two-dimensional flow the grid of Mach lines (hereafter called the Mach net) is determined from a velocity hodograph which is independent of the initial boundary conditions, and is therefore a fixed entity for all nozzles. In the case of rotationally symmetric flow the hodograph is dependent upon the boundary conditions and must, therefore, be determined for each expansion

* This paper is a summary of work done by the University of Washington Aeronautical Laboratory under Engineering Experiment Station Project No. 34, and was originally published as U.W.A.L. Report 303.[3]

angle. The velocity vectors in the hodograph plane (hereafter called the Velocity net) can be determined only when a Mach net is known. However, as in the case of two-dimensional flow, the Mach net is determined from the Velocity net.

Briefly, the Sauer method for determination of the Mach net is as follows: First, assume a Mach net for the conical flow and from it compute a Velocity net. Then, from the Velocity net, compute a new Mach net. The second Mach net is then used to correct the Velocity net, and so on. Each computation brings the Mach net nearer to the correct pattern, and the process is continued until two successive computations lead to the same Mach net. Thus far the process has been used to determine the Mach net in the conical expansion only. It is now necessary to find the transition contour which leads the flow from the conical expansion into the uniform, wave-free, parallel flow which is desired in the test section. Here it is necessary to specify the velocity vector in the final flow and compute by successive approximations the Velocity net and Mach net in the transition region. When the Mach and Velocity nets have been determined to the desired degree of accuracy, the direction of the Velocity net in each mesh of the Mach net is then known. The boundary of the transition region is then determined by extending the contour from the expansion section through successive meshes of the Mach net, requiring only that the boundary be parallel to the local velocity vector.*

An analytic solution of the characteristic equations, which is made possible by certain simplifying assumptions, has been suggested by Foelsch.[2] Determination of the nozzle boundary by the Foelsch method requires only a fraction of the time involved in the computation by the Sauer method. The analysis begins with radial conical flow as in the Sauer method. The flow enters the nozzle at the arc TR (Fig. 1) with sonic velocity and proceeds to the right with conical expansion until a Mach line AE is reached. The expansion of the flow along the Mach lines in the region TRAE is given by the equation

$$d\phi = \pm \frac{dw}{2w} \cot \mu$$

At the point E the design Mach number has been reached, and it is desired to put an end to the expansion. Hence it is required that Mach line EB be a straight line at an angle μ_E to the axis of symmetry.

In order to convert the conical flow into uniform, parallel, wave-free flow, the boundary must follow

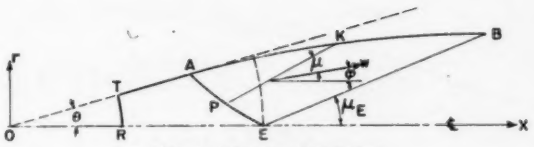

FIG. 1. FOELSCH METHOD

the transition curve. Any point P on the curved Mach line AE will be intersected by a member of the other family of characteristics, such as the Mach line PK. Such a Mach line can, of course, be represented by the characteristic equations of axially symmetric flow:

$$\frac{dy}{dx} = \tan (\phi + \mu)$$

$$\frac{dy}{y} = \left(\frac{dw}{w} \cot \mu - d\phi\right) (\cot \mu + \cot \phi)$$

These two equations relate the four quantities w, ϕ, x, and y; and the functions $w(x)$, $\phi(x)$, and $y(x)$ cannot be found unless a third relationship exists. In the Foelsch method this third relation is established under the assumption that the change in the velocity vector, Δw, along the Mach line PK is very nearly equal to that at the point P. Then,

$$M = M_p + \Delta M$$

$$\phi = \phi_P + \Delta\phi$$

where ΔM and $\Delta\phi$ are assumed small enough that second order terms $(\Delta M)^2$, $(\Delta\phi)^2$, $(\Delta M \Delta\phi)$ may safely be neglected. In the derivation[2] the relations are solved under the assumption that the first order terms (ΔM), $(\Delta\phi)$ are zero also, that is, that M and ϕ are constant along the curved Mach line PK. By means of these approximations the relation between x and y, ϕ, and M are established.

The detailed steps in the process for finding the nozzle coordinates are listed in Reference 2 and are easily carried out. The resulting nozzle boundary is plotted in Fig. 2, in comparison with that obtained from Sauer's method. It will be noticed that the discrepancy in the contour is quite large.

By means of sample measurements of the flow field obtained by Sauer's method, it is found that the change in Mach number along the curved Mach line PK varies from 1 per cent to 5 per cent. In a similar fashion, the change in flow direction varies from 12.5 per cent to 27.8 per cent. Thus, it would appear that the omission of first order differences along the Mach line PK is not justified. Although the Foelsch method requires very little time, it was concluded, as a result of this comparison, that the

* A detailed solution by the Sauer method will be found in the Appendix of the original report.[3]

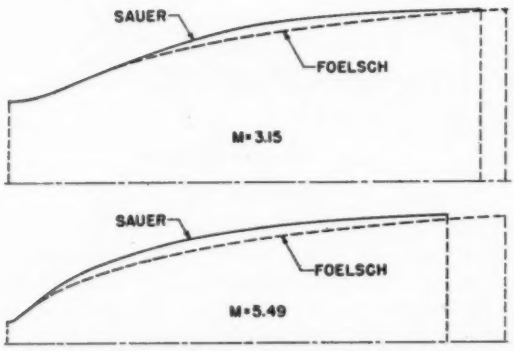

FIG. 2. COMPARISON OF NOZZLE ORDINATES

predicted profile is not sufficiently accurate for use for a supersonic wind-tunnel nozzle.

Nozzle ordinates for Mach numbers 3.15 and 5.49 are presented in Table I. Comparisons made between the methods of Sauer and Foelsch indicate that Sauer's method, although tedious, is the best practical approach to the theoretical flow condition. With reasonable care in the graphical construction the accuracy of the design can be considerably enhanced by increasing the number of meshes in the final Mach net.

Inasmuch as the Mach net in the conical portion is a function of the expansion angle only, the writers believe that the publication of such data in tabular form should eliminate the major portion of the labor involved in using Sauer's method in all subsequent computations.

TABLE I

NOZZLE ORDINATES FOR 3-DIMENSIONAL NOZZLES

x	r		x	r	
	$M=3.15$ $\theta=12.5°$	$M=5.49$ $\theta=20°$		$M=3.15$ $\theta=12.5°$	$M=5.49$ $\theta=20°$
0.000	.730	.248	3.500	1.281	1.132
.063	.....	.257	4.000	1.344	1.197
.125	.732	.278	4.500	1.395	1.244
.250	.736	.324	5.000	1.437	1.285
.375	.744	.370	5.500	1.470	1.326
.500	.757	.415	6.000	1.494	1.359
.625	.773	.460	6.500	1.512	1.386
.750	.793	.505	7.000	1.525	1.410
.875	.813	.550	7.500	1.533	1.433
1.000	.835	.593	8.000	1.538	1.454
1.250	.885	.672	8.250	1.539	.....
1.500	.939	.740	8.500	1.540	1.471
1.750	.993	.804	9.000	.....	1.480
2.000	1.040	.867	9.500	.....	1.489
2.500	1.129	.971	10.000	.....	1.498
3.000	1.209	1.060	10.421	.....	1.500

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BILLIG LECTURES ON CONCRETE

Professor Kurt Billig of Victoria University, Manchester, England, presented two lectures on November 16 to the students, faculty, and guests of the Department of Civil Engineering, the first on the subject of corrugated concrete roof construction and the second on the subject of prestressed concrete structural members. Professor Billig drew upon his broad experience in these fields to present a rather complete picture of the design, construction procedures, and engineering problems involved in these two types of construction which have been used in the United States only to a small degree.

The corrugated roof is constructed in a manner which reduces the dead load moments in the concrete shell structure to almost zero. The concrete shell structure is supported by a series of parallel arched bents, over which is draped a strong fabric mesh cloth made of a tough fiber such as hemp. The sag of the cloth between each pair of bents is a catenary curve in shape. The concrete and reinforcing steel are applied on top of this cloth in such a way as to maintain the catenary shape of the roof corrugations. Since the only moments in this type of roof structure arise from the live loads, the concrete shell is often no thicker than 1½ inches. This type of construction is useful in buildings where a large clear floor space without intermediate columns is required, and has been used for airplane hangars and industrial buildings.

In describing the ways in which prestressed concrete members were being used in Europe, Professor Billing showed slides of bridge girders, transmission line bents, railroad ties, and beams of various shapes. The methods of prestressing the reinforcing steel and of pouring the members was well illustrated in his slides. The characteristics of structural members designed so that prestressing places all the concrete in compression were very clearly indicated by the action of a prestressed concrete beam which was as flexible as a wood plank.

ELECTROTHERMIC PRODUCTION OF SODIUM*

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G. L. PUTNAM
Research Associate in Chemical Engineering

C. S. Lin

Introduction

Tens of thousands of tons of sodium metal are used annually for the production of tetraethyl lead and myriad other uses. On a volume basis, for example, far more sodium is used than nickel. Present methods for sodium production are electrically inefficient, small units only can be employed, and maintenance and labor costs are large.

The present study had for its purpose the production of sodium by carbon reduction of soda ash. The equilibrium temperature of the reaction

$$Na_2CO_3 + 2\,C \rightleftharpoons 2\,Na + 3\,CO$$

was calculated to be 1080° C. The reverse reaction temperature range was experimentally found to be 1100° to 700° C. In order to separate sodium metal, it was therefore necessary to cool rapidly the gases issuing from the furnace. The result was that either pure sodium was obtained at low yields, or an impure product, at moderate conversions.

Accordingly, in subsequent work, instead of attempting to distil the sodium from the melt, the writers studied extraction of the metal with molten lead. The largest industrial use of the alkali metal, tetraethyl-lead production, is in the form of a 5 per cent sodium-lead alloy.

Procedure

Into graphite crucibles with closely fitting lids were placed charges consisting of 140 grams of anhydrous sodium carbonate, 15 grams of pulverized charcoal, and 140 grams of lead. A heavy-duty nichrome resistance furnace served as the heat source. The melt was vigorously stirred with a stainless-steel motor-driven impeller. The Barber and Kilthoff method[1] was used for analysis of the sodium content. The results are presented in Table I.

As shown by Table I, the maximum sodium content of the alloys was 1.91 per cent, when charges were heated at 1010° C for 110 minutes with stirring.

By variation of a two-hour heating cycle so that the temperature was gradually increased from 930°-949° C to 1005°-1024° C, alloys having sodium contents of 2.71 to 2.96 per cent were produced.

G. L. Putnam

TABLE I

EFFECT OF STIRRING ON SODIUM CONTENT IN LEAD ALLOYS

Expt. No.	*Temp. (°C)*	*Time (min.)*	*Sodium (%)*
15	1010	30	0.71
14	1020	30	0.87
24	1010	80	1.25
25	1015	80	1.32
16	1010	100	1.64
20	1015	100	1.47
14	1020	100	1.12
†23	1010	100	1.04
31	1005	110	1.79
22	1010	110	1.91
†36	1010	110	1.30
32	1015	110	1.52
18	1020	110	1.30
34	1010	120	1.80

† Experiments were made without stirring. No excess sodium carbonate was added.

Discussion

The greatest difficulty encountered in the electrothermic production of sodium from sodium carbonate and carbon was the separation of sodium vapor from carbon monoxide. This is actually the same kind of trouble which delayed the development of electrothermic manufacture of magnesium from magnesium oxide and carbon. Preliminary ex-

* Condensed from the thesis of the same title submitted by C. S. Lin for the degree of M.S. in Chemical Engineering, and based on research carried on by the joint authors.

periment and thermodynamic calculation showed that the difficulty of reverse reaction of metallic vapor with carbon monoxide was not as severe in the case of sodium as in the case of magnesium. Furthermore, the reaction temperature of sodium carbonate with carbon is much lower than that of magnesium oxide with carbon. The by-product carbon monoxide might be used as the quenching medium to separate sodium effectively from carbon monoxide. Experiments also indicated that the conversion of this reaction was high. If a proper quenching method with carbon monoxide as the quenching medium could be devised, the electrothermic manufacturing of sodium from sodium carbonate would be promising. The graphite resistance type of electric furnace, a diagram of which is shown in Fig. 1, was found to be suitable to the electrothermal production of sodium on a laboratory scale and no complications were experienced in its operation. Resistance furnaces of this nature can be easily built on a commercial scale.

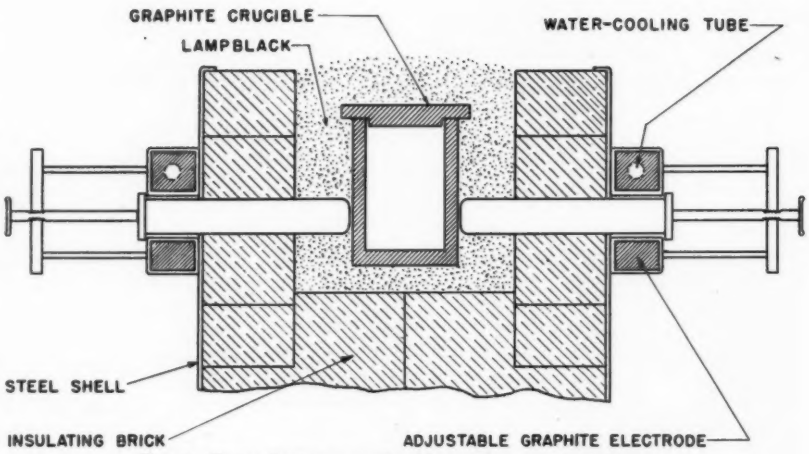

FIG. 1. CROSS SECTION OF GRAPHITE RESISTANCE FURNACE

Sodium-lead alloys of 3 per cent sodium content have been prepared with use of the same furnace. Appreciable amounts of sodium vapor escaping with carbon monoxide left the furnace without being absorbed by the molten lead. If an efficient device could be made to absorb the residual sodium vapor from the carbon monoxide evolved, the sodium content of the lead alloys could be increased. Flashing of the hot 3 per cent sodium-lead alloys directly from the furnace in vacuum might also prove to be an economical method for electrothermally producing sodium from sodium carbonate. A thorough investigation of sodium manufacture by means of lead alloys could be made, if the vapor-pressure data of sodium-lead alloys were available. According to present plans, therefore, before further investigation of this problem is undertaken the vapor pressures of sodium-lead alloys at temperatures within the range of 700° to 1100° C will be measured, and the work will be continued from that point.

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RIPPLES FROM WAVE MACHINE REACH SHORE OF EUROPE

The article by F. J. Sines, "Laboratory Control of Ocean Waves," reprinted from the *Engineering News-Record* of December 9, 1948, in the *Trend* of April, 1949, described the design of apparatus to produce waves conforming to theory. Since then the author has been asked for permission to reprint the paper in *The Dock and Harbour Authority*, a British journal with world-wide circulation, and, more recently, in *Informes de la Construcción*, a Madrid publication devoted to scientific and technical progress of value to those interested in construction.

The wave machine was constructed under Engineering Experiment Station Project No. 7. Mr. James Harland was Research Fellow in 1948-49, and the work is being continued by Robert Hager, Research Fellow for the current year. Prof. R. G. Hennes supervises the project.

In its verification tests the apparatus produced waves whose length and period were within 5 per cent of their theoretical values. Recently the Army Engineer's Office made use of the installation to study levee revetments. Possible application to wave problems in the Gulf of Mexico has been the subject of another recent inquiry.

Bureau of Ships Contracts with Station for Structural Tests

The Engineering Experiment Station was recently notified by the Bureau of Ships, Navy Department, of the award of a contract to investigate methods of welded reinforcement around openings cut in structural members. The investigation will be carried out in the Structural Research Laboratory of the Department of Civil Engineering under the supervision of R. A. Hechtman, Associate Professor of Structural Research. The present contract involves an amount of $14,000 and will terminate on July 1, 1950.

Openings in ship structural members introduce a certain amount of structural weakness which is caused both by the loss of material and the attendant stress concentration brought about by the geometrical discontinuity. The objective of this study is to collect basic experimental data on the optimum shape of the opening, and the most effective disposition of the reinforcing material in order to assure maximum ductility and maximum strength.

The size of the specimens to be tested will require the use of the 2,400,000-lb capacity universal testing machine. Large tension tests will be made of structural steel plates 36 inches wide and one-quarter inch thick. Centrally located in each plate will be an opening 9 inches in width. The first tests will investigate the effect upon the strength, stress distribution, and ductility of round and square openings without reinforcement. Subsequent specimens will have either round or square openings with reinforcement of one of three types: ring bars, doubler plates, or insert plates. These exploratory tests will be used to plan a comprehensive program of tests.

The strain distribution in the critically stressed areas will be determined in these tests by extensive electric strain gaging. The data from these measurements will be used to develop rational or semi-rational methods of design for members containing square or circular openings.

Tests of a small number of specimens will be made at low atmospheric temperatures. It is possible that the restraints produced by welding and the notch effect of the opening may cause brittle fractures with an accompanying loss of ductility at the lower temperatures.

ENGINEERING COLLEGE RESEARCH COUNCIL — NORTHWEST MEETING

At a meeting held in Spokane November 13, 1949, representatives from the Montana School of Mines, Montana State College, University of Idaho, Washington State College, British Columbia Research Council, University of Washington, and Oregon State College established the first organization for the coordination of industrial and engineering research conducted in colleges and universities in the Pacific Northwest. Those present at the initial meeting of this group included the following: President F. J. Thomson, Montana School of Mines; Dr. L. Berg, Montana State College; Dr. L. C. Cady, and Dr. C. O. Reiser, University of Idaho; Dr. W. A. Pearl, Prof. E. B. Parker, and Prof. H. J. Dana, Washington State College; Dr. S. E. Maddigan, British Columbia Research Council; Prof. S. H. Graf, Oregon State College; Prof. F. B. Farquharson, and Prof. W. W. Philbrick, University of Washington.

The organization has been established to promote fundamental and applied industrial and engineering research, to interchange and publish information on research work in progress, to encourage development of regional resources, to assist in solving regional industrial and engineering problems, and to familiarize regional industry with the equipment and personnel locally available for solving industrial and engineering research problems. Pro tem officers of the organization are Prof. F. B. Farquharson, chairman, and Prof. W. W. Philbrick, secretary.

This organization is the outgrowth of the June, 1949, meeting of the American Society for Engineering Education held in Bozeman, Montana, at which the need was stressed for an organization to coordinate engineering and industrial research in institutions in the Pacific Northwest region.

Discussions at this first meeting were devoted to such subjects as types of contracts and financial arrangements with cooperating industries, means of drawing the attention of industries to research facilities available, patent policies, and methods of payment and retirement and tenure plans for research personnel.

The next meeting of the organization will be held in Seattle on June 18, 1950. At that time a formal request will probably be made for recognition as the Pacific Northwest Section of the Engineering College Research Council. It would thus become the first regional unit of that council.

Notes and Comments

NEW RESEARCH PROJECTS

Project No. 75. Construction of a Thermal Conductivity Hot Box. W. W. Philbrick, Assistant Professor of Mechanical Engineering, Supervisor.

Project No. 79. Contraction Straightening of Structural Steel. W. W. Philbrick, Assistant Professor of Mechanical Engineering, Supervisor; H. L. Harrison, Research Fellow.

Project No. 80. Structural Research on Effect of Cutouts on Large Tension Members. R. A. Hechtman, Associate Professor of Structural Research, Supervisor. Sponsored by the Bureau of Ships, U.S.N.

Project No. 81. The Subsoil Factor in Earthquake Hazard. R. G. Hennes, Professor of Civil Engineering, Supervisor; Harold Mason, Horton Dennis, K. H. Chang, Research Fellows. Sponsored by the Bonneville Power Administration.

Project No. 82. Absorption with Reversible Chemical Reaction. R. W. Moulton, Associate Professor of Chemical Engineering, Supervisor; J. C. Hunt, Research Fellow.

Project No. 83. Chemical Utilization of Coal. H. K. Benson, Professor Emeritus of Chemical Engineering, Supervisor; L. A. Conradi, Research Fellow.

Project No. 84. The Economic Place of Steam-Power Generation in the State of Washington. F. D. Robbins, Instructor in Electrical Engineering, Supervisor; Paul Leach, Research Fellow.

EFFECTS OF LOW TEMPERATURES ON ELECTRIC STRAIN GAGES

(*Continued from page 15*)

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ENGINEERS IN THE NEWS

E. E. DAY, Assistant Professor of Mechanical Engineering, presided over a session of the meeting of the Society for Experimental Stress Analysis held in New York November 30–December 2, and also attended the meeting of ASME. In early September as one of 62 guest professors from schools in all parts of the nation, Professor Day participated in the second Timken anti-friction symposium at the Timken Roller Bearing Co., in Canton, Ohio.

H. E. WESSMAN, Dean of the College of Engineering, is coauthor with Prof. T. C. Kavanaugh, of Penn State, of "End Restraints on Truss Members," which appeared in the September issue of the *Proceedings of ASCE*.

J. H. DWINNELL, Assistant Professor of Aeronautical Engineering, is the author of a book, *Principles of Aerodynamics*, issued by McGraw-Hill Book Company in November.

BEN BRYANT, Research Fellow in the Engineering Experiment Station 1947-48, is now part-time instructor in the Yale School of Forestry while completing work for his doctorate.

ROBERT OLIVER and **NORMAN GRIMSBY,** Station Research Fellows in Chemical Engineering in 1948-49, are taking graduate work toward a doctorate degree at M.I.T.

NEW PUBLICATIONS

Reprint No. 26. "A Study of Diffusion in Agar Gels by a Light Absorption Method," V. F. Felicetta, A. E. Markham, Q. P. Peniston, J. L. McCarthy, *Jour. Am. Chem. Soc.*, Vol. 71, p. 2879, 1949.

Reprint No. 27. "Graphical Analysis of Tuned Coupled Circuits," A. E. Harrison, N. W. Mather, *I.R.E. Proceedings*, Vol. 37, No. 9 (September, 1949).

Reprint No. 28. "Induction Furnace for High-Temperature Ceramic Research," P. D. Johnson, *Jour. Am. Cera. Soc.*, Vol. 32, No. 10, October, 1949).

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